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in Saskatchewan

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User Manual

9 Water Quality

This report was prepared for the Mackenzie River Basin Committee. Any conclusions, recommendations or opinions expressed herein are those of the authors and are not necessarily the same as those of the Committee.

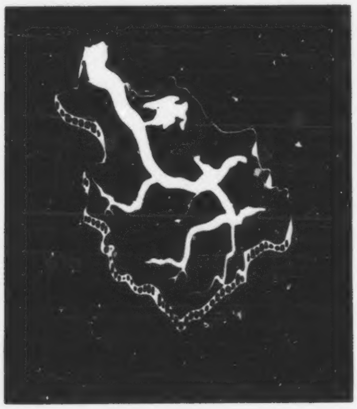
Cover Photo: Mackenzie River at
Fort Simpson, Northwest
Territories, looking downstream

Mackenzie River Basin Committee

Water Quality

Mackenzie River Basin Study Report Supplement 9

A report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin. This report is the fifth in the Water Quality Interpretive Report series published by the Water Quality Branch, Inland Waters Directorate, Environment Canada.



Canada — Alberta — British Columbia — Saskatchewan
Northwest Territories — Yukon Territory 1985

Canadian Cataloguing in Publication Data

Main entry under title:
Water Quality

(Mackenzie River Basin Study report, Supplement, 9)

"A report under the 1978-81 Federal-Provincial Study Agreement respecting the water and related resources of the Mackenzie River Basin."

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Cat. No. En 37-22/9-1985

ISBN 0-662-14021-4

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Your file Votre référence

Our file Notre référence

March 22, 1985

Mr. G. Lewis
Secretary of Mackenzie River
Basin Committee
Mackenzie River Basin Study
Inland Waters Directorate
Environment Canada
1st Floor, 1901 Victoria Avenue
Regina, Saskatchewan
S4P 3R4

Dear Mr. Lewis:

Re: Mackenzie River Basin Study Program 1978-81
Supplement 9: Water Quality

We are pleased to submit herewith the Water Quality Interpretive Report for the Mackenzie River Basin. We appreciated the opportunity to work on this assignment.

If you have any questions regarding the report, please do not hesitate to contact us at your convenience.

Yours truly,

DBlachford
D.P. Blachford

A. Demayo

Wm. Gummer

Acknowledgments

The Mackenzie River Basin Water Quality Report was prepared by the staff of the Water Quality Branch, Headquarters. The assistance of Water Quality Branch, Western and Northern Region, in critically reviewing all drafts of the report is gratefully acknowledged. The Mackenzie River Basin Committee reviewed and provided valuable comments on the final draft document.

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Abstract

This report describes the general state, seasonal and spatial trends of many physical, chemical, nutrient, metal and organic contaminant parameters of the major subbasins of the Mackenzie River basin. This is the only comprehensive assessment of water quality data that have been collected in the basin since the early 1960s by federal and provincial governments.

The report recommends changes to the present monitoring design and strategy to reflect current requirements and water quality issues. Particular emphasis is given to sampling medium and frequency, uniformity of analytical techniques and basin coverage, with the intention of increasing the amount of information that can be obtained from the collected data.

Résumé

Ce rapport traite de l'état général, des tendances saisonnières et spatiales de nombreux paramètres physico-chimiques, des matières nutritives, des métaux et des contaminants organiques dans les principaux sous-bassins du bassin hydrographique du fleuve Mackenzie. Il s'agit de la seule évaluation complète des données de la qualité de l'eau recueillies dans ce bassin depuis le début des années 1960 par les gouvernements fédéral et provincial.

Le rapport recommande que l'on modifie la conception et la stratégie de surveillance conformément aux besoins actuels en information et aux préoccupations en matière de qualité de l'eau. Il insiste particulièrement sur les milieux à échantillonner et la fréquence des échantillonnages, l'uniformité des techniques d'analyse et l'étude du bassin en entier, afin d'augmenter la quantité d'information que l'on peut tirer des données recueillies.

Executive Summary

This report describes the general state, seasonal and spatial trends of many physical, chemical, nutrient, metal and organic contaminant parameters of the major subbasins of the Mackenzie River basin. This is the only comprehensive assessment of water quality data that have been collected in the basin since the early 1960s by federal and provincial governments.

The Mackenzie River basin has been undergoing extensive natural resource development activity in recent years. The development of mining, oil, gas and hydroelectric power has accelerated at a marked rate. Our knowledge of the social, economic and environmental consequences of development, however, has not kept pace with the activities. Research in the basin has largely centred on specific problems to advance industrial enterprises (Environment Canada, 1983). There is a lag in the study of biological processes which must be understood to predict the effects of development. Damage to the northern ecosystem has profound local and widespread consequences and may last decades. A knowledge base of the northern environment is needed on which to build policies to ensure biological health in the region.

Current development issues in the basin include hydroelectric potential on the Liard and Slave rivers, flow regulation from lakes to provide storage for hydroelectric generation, water transfers from the Athabasca and Peace rivers to southern basins, the expansion of the Norman Wells oil field, and exploration and development of oil and gas in the Mackenzie delta (Environment Canada, 1983). The impact of these activities on the environment, and on the hydrologic system in particular, is difficult to predict without a clear understanding of the aquatic environment that can only be gained from a northern water quality database. An increase in the amount of research conducted in northern environments is required to augment the existing database so that environmentally sound decisions regarding safe development can be made.

Conclusions from interpretation of the existing water quality data in the Mackenzie River basin are the following:

1. Physical parameters and major ions show regional differences corresponding with the physiographic subdivisions of the basin. High turbidities characterize the subbasins in the Western Cordillera, levels of dissolved parameters are the highest in the Interior Plain, and low levels of the parameters occur in the Shield area. Rivers and lakes of all subbasins are dominated by Ca^{2+} and HCO_3^-. Spatial patterns of these parameters appear to be related to natural variations along the watercourse. Seasonal variations of the physical parameters and ions are related to the discharge regime. Concentrations of these parameters and their seasonal variations in the mainstem Mackenzie River are governed by the relative contributions of the tributaries and the effects of Great Slave and Great Bear lakes.

2. Nitrogen and phosphorus concentrations are highly variable within and between subbasins due to physical and geologic differences. Seasonal changes in nutrient species concentrations reflect the discharge regime and biological utilization patterns. The observed changes in nutrient concentrations over time may be due to analytical, natural and/or anthropogenic causes. A large portion of the measured nutrients are not available for biological uptake; this is evident in that the nutrient levels are not reflected by biological productivity. Insufficient data are available to permit evaluation of spatial and seasonal behaviour of nutrient species.

3. Concentrations of metals in the Mackenzie River basin are at natural levels and are largely in association with suspended solids. Athabasca and Great Slave lakes reduce the metal load to the Mackenzie River by serving as sediment settling basins for the Athabasca, Peace and Slave rivers. Metal concentrations show seasonal changes in response to the discharge and suspended sediment

regimes. Availability of the metals for biological uptake is not known.

4. Organic parameter data for the basin are almost entirely below detection limits in water. Detectable levels were observed for a few compounds during the open water period. Data availability does not permit evaluation of contaminant impact on the aquatic system, nor, with any certainty, of their presence in the aquatic environment.

5. Modifications are recommended to the present monitoring design and strategy to reflect current monitoring requirements and water quality issues. Particular emphasis is given to sampling medium and frequency, uniformity of analytical techniques and basin coverage, with the intention of increasing the amount of information that can be obtained from the collected data.

Introduction

1.1 The Mackenzie River Basin

The Mackenzie River is the longest river in Canada; it flows approximately 4000 km from the Finlay River headwaters in British Columbia to the Beaufort Sea. Draining almost 2 000 000 km^2, an area representing one fifth of Canada's total area, the Mackenzie River ranks seventh in the world for discharge volume and is surpassed in Canada only by the St. Lawrence River. The Mackenzie River basin encompasses great cultural, geographical and biological diversity and a wealth of natural resources. Perhaps the most important renewable resource in the Canadian North is water.

The water resources of the Mackenzie Basin form the backbone of human, plant and animal life in the North. Spring breakup and the snowmelt flood are the major hydrologic events each year in the basin. Physical and biological processes, upon which the productivity of the region directly depends, are regulated by these events. The biological productivity of the region determines the rate at which renewable resources along the river courses are produced. The environmental diversity along the waterways is greater than that of the surrounding land area; high productivity and a wide range of human uses therefore are also focussed in areas adjacent to aquatic resources.

The rivers, lakes and deltas of the Mackenzie Basin support a diversity of plant, fish, waterfowl and wildlife populations. Major flyways on the North American continent convene along the Mackenzie Valley; the deltas are staging and nesting grounds for the birds. Fish and sea mammals use the deltas for spawning, rearing and overwintering. A delicate balance is maintained between the populations and their habitat. Changes in the water quantity or quality, or disturbances to the natural environment, may have detrimental effects on the fragile northern ecosystem.

1.2 A Historical Perspective

Since early times, the Mackenzie River and its tributaries have played a leading role in shaping the character of the region. Until about two centuries ago, the basin was essentially a home for nomadic native peoples. Population centres started to emerge along the major rivers which were used as routes for the fur trade. Later, oil, gas and mining developments, dependent upon the river systems for transportation and hydroelectric power, rapidly expanded. The economic value of the basin and its importance to the nation were increasingly recognized.

From the turn of the century until World War II, issues of Canadian sovereignty were the principal concerns in the North. Priority was given to traditional forms of northern life and environmental quality as part of the strategies to advance jurisdictional claims in the Arctic. These priorities were maintained until new resource use alternatives emerged (Environment Canada, 1983).

From World War II to 1970, under northern resource policies, most of the North was open to all forms of resource use with few, if any, restrictions on their development. Conflicting uses and side effects of the uncontrolled exploitation led to many problems. In response to the emerging problems new regulations (Northern Inland Waters Act, Territorial Lands Act) were established to increase control over exploration and development, and a comprehensive policy statement on northern development was released by the Department of Indian and Northern Affairs in 1972.

1.3 Mackenzie River Basin Study Background

A significant step in coordinating resource development while preserving the value of the water resources was made in 1972 with the first intergovernmental seminar on the water resources of the Mackenzie Basin. As a result of the meeting, the Mackenzie Basin Intergovernmental Liaison Committee was formed to exchange information concerning project planning, research and potential developments. In 1977, the Liaison Committee was re-established as the Mackenzie River Basin Committee.

The Committee embarked upon a three-year study program designed to increase the knowledge base of water and related resources in the basin. Work on the program was carried out by federal, provincial and territorial agencies as well as by universities and private consultants. The Mackenzie River Basin Study Report (1981), accompanied by eight supplemental volumes, is a report on the study program. This report, the ninth supplement, completes the supplemental volumes to the Study Report.

The need for an interpretive water quality study became apparent early in the study program. Initial work towards this goal included the completion of "Summary of Available Water Quality Information 1979" prepared by the Water Quality Branch, Inland Waters Directorate, which provided the basis for a computerized water quality database for the basin. The document, produced under contract for the Hydrologic System Advisory Group as part of the Mackenzie River Basin Study Program 1978-1981, summarizes the water quality data pertaining to the basin. In the preparation of this report, water quality data provided by the Environment Canada National Water Quality Database (NAQUADAT), Department of Indian and Northern Affairs (DINA), the Alberta and British Columbia governments and private sources were collected, assessed, tabulated and discussed. In all, information from 405 stations was presented after selection criteria had been applied to a complete list of available stations. The availability of data to describe the influence of existing and proposed developments was reviewed. Present and possible future data gaps were highlighted, along with recommendations for future action.

At the request of the Hydrologic System Advisory Group, the Water Quality Branch then published a compendium entitled "Water Quality Data Mackenzie River Basin 1960-1979." The report contains statistical summaries of water quality data for 448 river and lake stations sampled by federal and provincial agencies. The publication was intended primarily as a reference of water quality data and forms the basis for the present water quality interpretive report.

1.4 Terms of Reference

This report was written under contract to the Hydrologic System Advisory Group. It is published as Supplement 9 of the Mackenzie River Basin Study Report and as report No. 5 of the Water Quality Branch Interpretive Report series. The Water Quality Branch identified what could be achieved with the existing database. This was accepted by the Advisory Group as the terms of reference for the report:

(1) an analysis of interparameter and parameter-discharge relationships within each drainage subbasin
(2) a characterization and comparison of the chemical composition of waters in each drainage subbasin
(3) an evaluation and discussion of water quality in the Mackenzie River basin with respect to water-use guidelines
(4) an identification of seasonal variations and possible trends in water quality at selected sites
(5) a synthesis of the surface water quality of the Mackenzie River basin
(6) a reference list of cited references.

1.5 Objectives

Data pertaining to physical, major ion, nutrient, metal and organic parameters collected from 1960-1979 were evaluated for each of the subbasins. Given the terms of reference and the characteristics and limitations of the data, the objectives of this report are

(1) to provide a comprehensive description of the nature of the available data for each of the parameter groups
(2) to characterize and compare the physical and chemical composition of river and lake water in each subbasin
(3) to identify and compare spatial and seasonal variations of the parameters at a few sites in each subbasin
(4) to identify any trends over the period of record
(5) to analyze parameter and parameter-discharge relationships within each subbasin

(6) to synthesize surface water quality data and provide an ecological perspective of water quality in the Mackenzie River basin

(7) to evaluate tentatively the compliance of the basin water quality with aquatic life guidelines.

1.6 Environmental Setting

The Mackenzie River basin represents a unique northern environment. The diverse bedrock formations dominate the physiography of the region. The harsh climate, varied soil types and distribution of permafrost affect and are affected by the vegetation, which in turn plays a major role in supporting wildlife populations. The rhythm of life in the North is controlled by the seasons and by the hydrology of the river and lake systems.

A variety of resource development activities have a large presence in the North. While the immediate economic benefits may be favourable, the long-term impact on the environment is unknown. A balance is desirable between preserving native culture and enhancing economic conditions.

The physical features and the socio-economic and cultural elements of the basin are closely interwoven. Because of the effects of the former and dependence of the latter upon the water quality of the basin, these factors are reviewed in Appendix A. The Mackenzie River Basin Study Report Supplements (Mackenzie River Basin Committee, 1981) discuss physical elements of the basin in detail.

Water Quality Data

The remote environment and vastness of the Mackenzie River Basin often necessitated sampling strategies and practices that hindered data interpretation. Many of these factors are discussed below to inform the reader about the inherent limitatons in the data interpretation.

2.1 Sampling Aspects

Monitoring by the agencies was carried out over the period of record on a quarterly or monthly basis during the open water period, depending upon the parameters and sites sampled. Due to difficulties in sampling in the northern environment, monitoring during the winter has been sporadic and infrequent and never monthly. The low variability of many of the water quality parameters under ice cover minimizes the effect of this limitation on describing basin water quality.

Frequency of sampling of parameters was established by the agencies and was based upon management resources, the rationale of the collection program (e.g., long-term trend monitoring, impact assessment), and parameter characteristics. Site sampling frequency was based upon site importance and accessibility. Appendix B indicates the variation of sampling frequency for major ions at a few sites in the Mackenzie Basin. Figure 2.1 shows the variable frequency of sampling of a range of parameters at a single site. The figure indicates frequencies for the Athabasca River at Athabasca site. The major ion and nutrient parameters were clearly analyzed more often than the metal and organic parameters. The frequency of sampling at this site is much higher for all parameters than at any other site in the Mackenzie Basin.

It has not been specifically determined whether the spring flow, which profoundly affects the magnitude and variability of many of the water quality parameters, was adequately addressed by the sampling

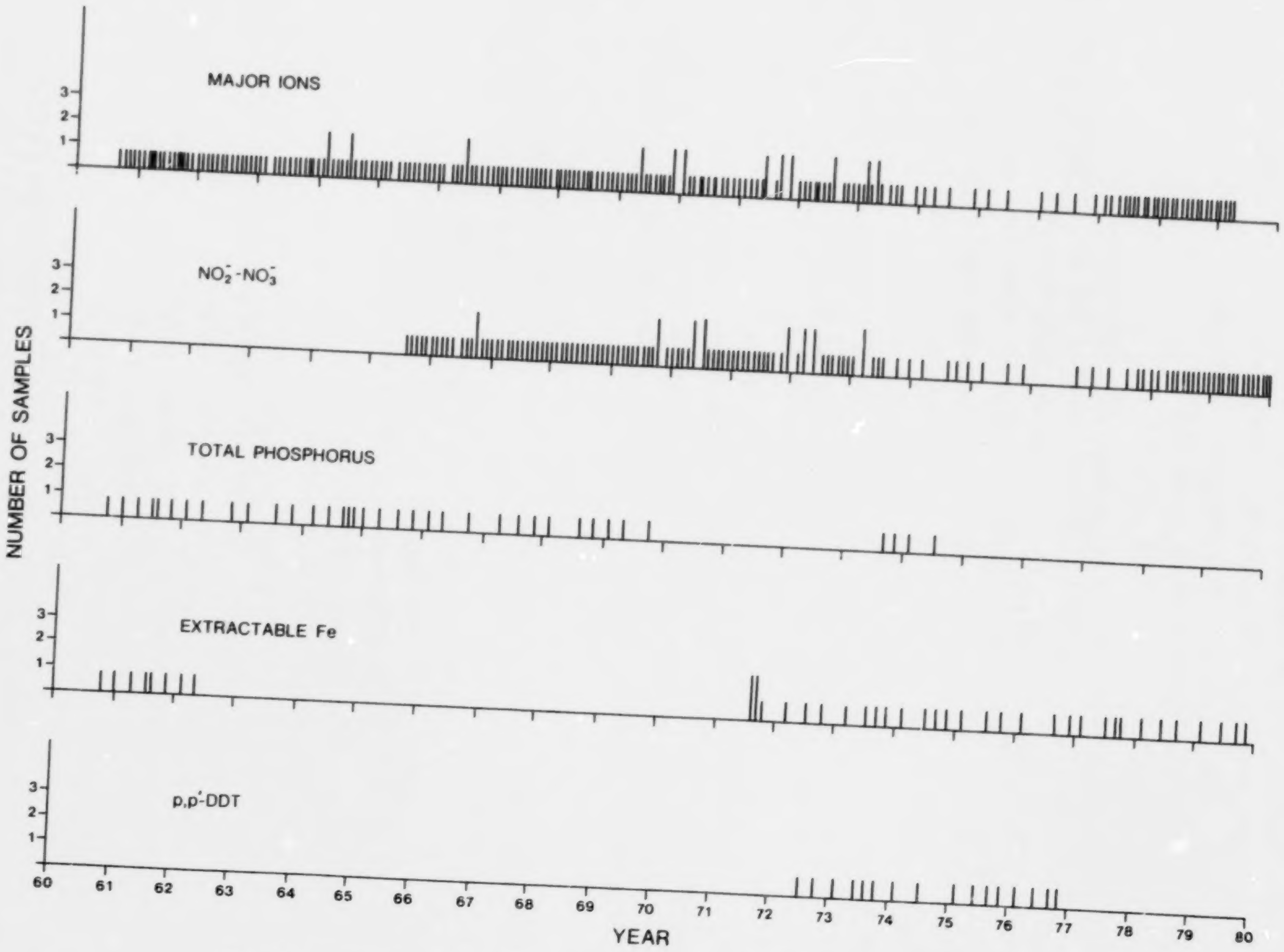


Figure 2.1 Frequency of sampling of selected parameters at Athabasca River at Athabasca (00AL07BE0001).

frequency. Unusually high water levels in the Fort Good Hope reach of the Mackenzie River, evident by the ice drive markings on the hydrometric station on the river bank, were not regularly sampled for water quality for logistic reasons.

The exact sampling location at a particular site was determined by accessibility and by the location of hydrometric gauging stations. Samples were depth-integrated, i.e., one sample consisted of water collected theoretically from all depths of the water column, and were instantaneous. Given the large widths and depths of rivers in the basin (the Mackenzie River at Norman Wells, for example, is about 5 km wide and 100 m deep), the representativeness of the collected samples is uncertain. Where possible, samples were collected midstream. If a boat was not available and/or seasonal conditions prohibited midstream collection, however, samples were taken near the shore. The longitudinal, spatial and temporal variability of many of the water quality parameters was accepted, as the purpose of the sample collection strategy was to determine the major differences between sites and major changes over time.

The lag time between sample collection and analysis at the laboratory is a factor that may affect the quality of data. Water Quality Branch samples in most cases were collected by Water Survey of Canada personnel from the hydrometric subregions of the basin. As soon as possible after collection, samples were packaged and shipped via commercial air carrier to the laboratory in Ottawa until 1967 and thereafter to Calgary. The length of time from sample collection to arrival at the laboratory may vary from a few days to a couple of weeks, depending upon the site locations, length of sampling run and shipment times. Once at the laboratory, samples were analyzed immediately for some parameters and later (up to a few months) for other parameters. Samples were analyzed sooner after collection for nutrients than for metals because samples for the latter were preserved and were stable for a longer time.

Water samples collected for analysis of dissolved (soluble) components were not, for the most part, filtered in the field at the time of sampling. For a short time in the 1970s, samples collected north of 60° were filtered in a field laboratory (Hay River) before submission for analysis; in these cases the filtering would have been carried out within approximately 24 h of collection. Technical difficulties, such as extreme winter temperatures and few daylight hours in the winter, and time limitations of personnel and aircraft use, prohibit on-site filtering. Delays in sample filtering can significantly alter the species proportions and abundance of dissolved substances. As time delays vary between sites and visits and at each site, comparison (spatial and temporal) of dissolved parameters is tenuous. Because of the uncertainty of the magnitude and direction of change in concentration of dissolved substances and dissolved metals in particular, the latter are not discussed in this report.

Contamination of samples may occur during collection, transport and analysis. The problem is difficult to document, as it may occur to varying extents in different areas and for different parameters. Mercury contamination of water quality samples has been a problem; mercury transported by Water Survey of Canada personnel for and leaked from manometers is a known cause. As it is not possible to identify from the data where contamination has occurred, mercury concentrations (total, extractable, dissolved) are not discussed in this report.

2.2 Analytical Methodology

Major changes in analytical methodology that affect the resulting data occurred over the period of record. These included changes in the laboratory locations, in technical procedures and in corresponding detection limits.

Several changes in locations of analytical laboratories occurred over the period of record. Block (personal communication, 1983) has found changes in water quality concentrations over time that parallel changes in federal laboratory locations. Federal samples collected in the Mackenzie Basin prior to 1967 were analyzed at the Energy, Mines and Resources laboratories in Ottawa. From May 1973 to August 1974, a regional field laboratory was functional in Hay River; samples collected north of 60° were pretreated there prior to being forwarded for complete analysis at a laboratory in Calgary. Between October 1974 and July 1978, some sample analyses were performed in a Yellowknife laboratory and analyses for remaining parameters were carried out in Calgary. As of 1978, all federal analyses were done in the Calgary laboratory.

Changes in analytical methodology occurred for several reasons, including limitations in the prevailing methodology, equipment requirements or method obsolescence, automation and the introduction of methods and/or equipment which permitted the lowering of detection limits. Samples collected from Athabasca River at Athabasca, for example, were anlayzed for nitrite-nitrates by four methods:

Method*	From	To
07108L	65-07-06	66-10-05
07105L	66-11-02	72-06-01
07106L	72-07-04	76-08-09
07110L	76-11-02	79-12-04

* Codes of the Water Quality Branch, Environment Canada.

Because of variations in the detection limits, all data files for each parameter were standardized by the Water Quality Branch. Various detection limits were on record which affect the limits that can be achieved. Loss of information occurred when recorded detection limits were lowered and when recorded values were blanketed by a higher limit. The values most affected by the changes are those for metals, organic parameters and nutrients that are present in the basin at low concentrations. Examples of changes in the data set, applied to data collected after September 1974, are shown in Table 2.1.

Table 2.1 Examples of Data Set Modifications Due to Changes in Detection Limits

Parameter	Recorded value	Standardized value
TOC (06001L)*	<0.1	<0.5
P (15363L)	<0.003	<0.001
(15255L)	<0.003	<0.002
TKN (07001L)	<0.1	<0.5
Extractable Cu, Pb, Zn, Cd	<0.002, <0.004	<0.001
Extractable Cr	<0.004, <0.015	<0.010
Extractable Ba	<0.04, <0.05	<0.1
Extractable Ag	<0.01, <0.05	<0.004
As (33103L)	<0.004	<0.005
(33104C)	<0.008, <0.0005	<0.001

* NAQUADAT parameter codes are given in parentheses.

NOTE: Changes effective as of September 1974.

2.3 Data Treatment

The report "Water Quality Data Mackenzie River Basin 1960-1979" (Water Quality Branch, 1981) was the database used for this study. Data were collected by federal agencies and the provinces of Alberta and British Columbia. All data were formatted to be compatible with data on the NAQUADAT system.

Data interpretation is organized according to the major subbasins of the Mackenzie River basin: Athabasca River, Peace River, Liard River, Hay River, Great Slave Lake, Great Bear Lake, Mackenzie River. In previous studies, the Hay River subbasin has been reviewed as part of the Great Slave Lake subbasin. Due to the many characteristics of the Hay River drainage basin that differ widely from those of the central and eastern portions of the Great Slave Lake drainage, it is appropriate in the present study to consider the Hay River as an individual drainage subbasin. All sites sampled in the subbasins, by government and private agencies for any length of record, are shown in Figure 2.2.

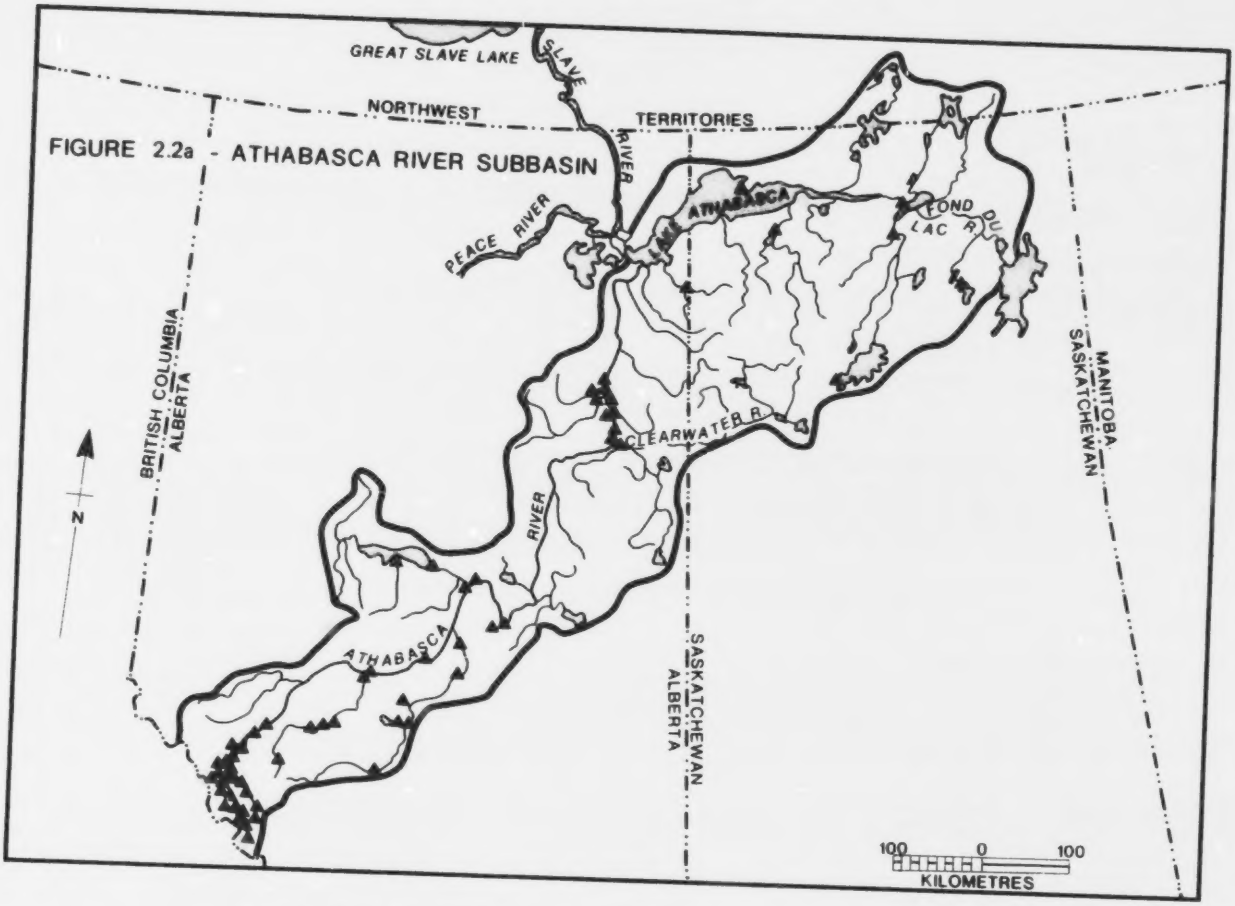


Figure 2.2 Water quality monitoring stations in the Mackenzie River basin, 1960–1979.

NOTE: Figure 2.2 is continued on pages 13, 14 and 15.

FIGURE 2.2b - PEACE RIVER SUBBASIN

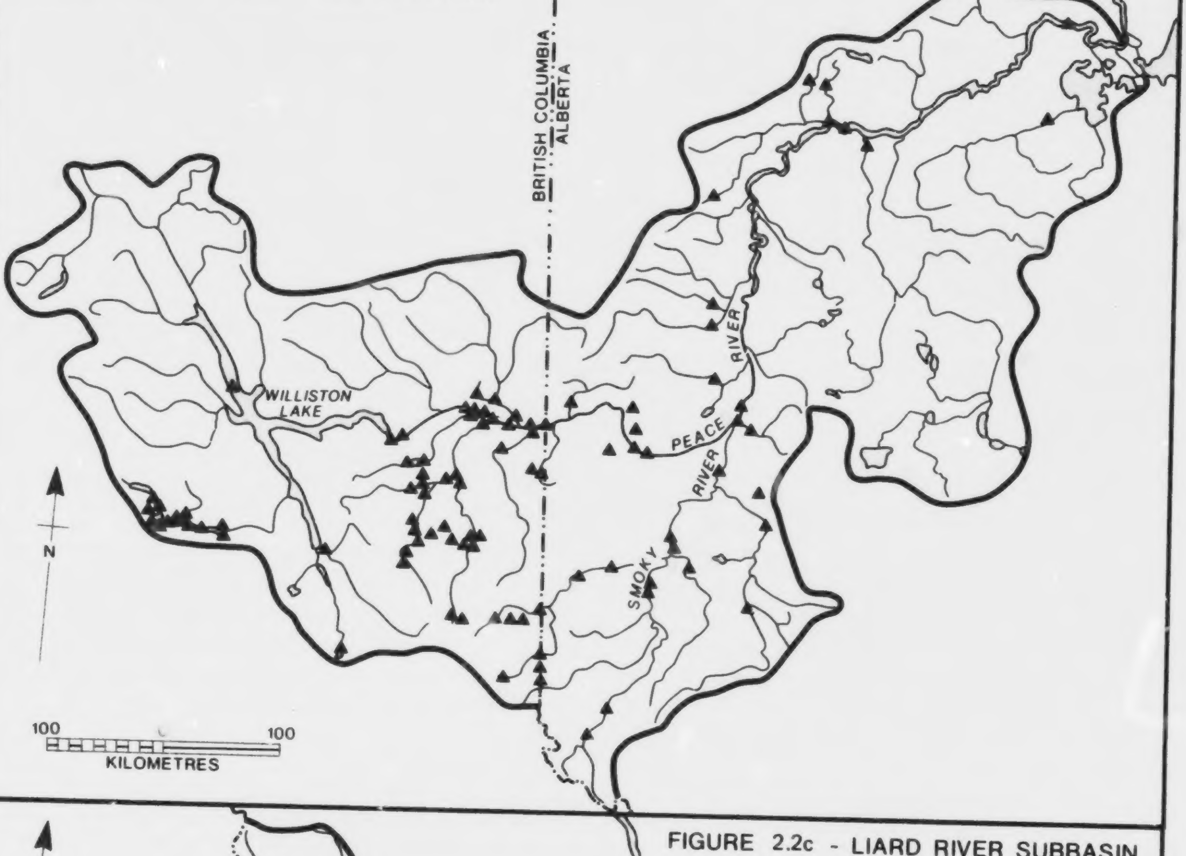


FIGURE 2.2c - LIARD RIVER SUBBASIN

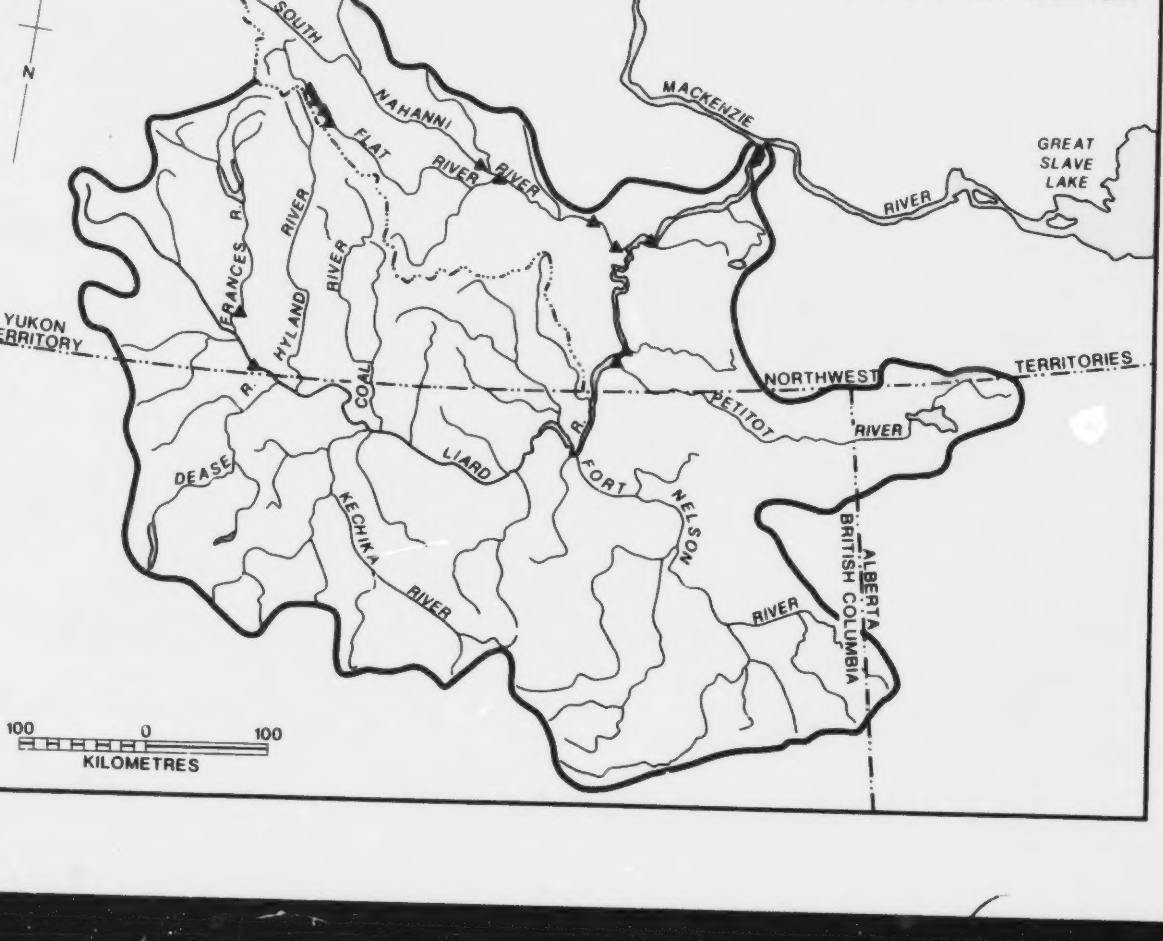


FIGURE 2.2d - HAY RIVER SUBBASIN

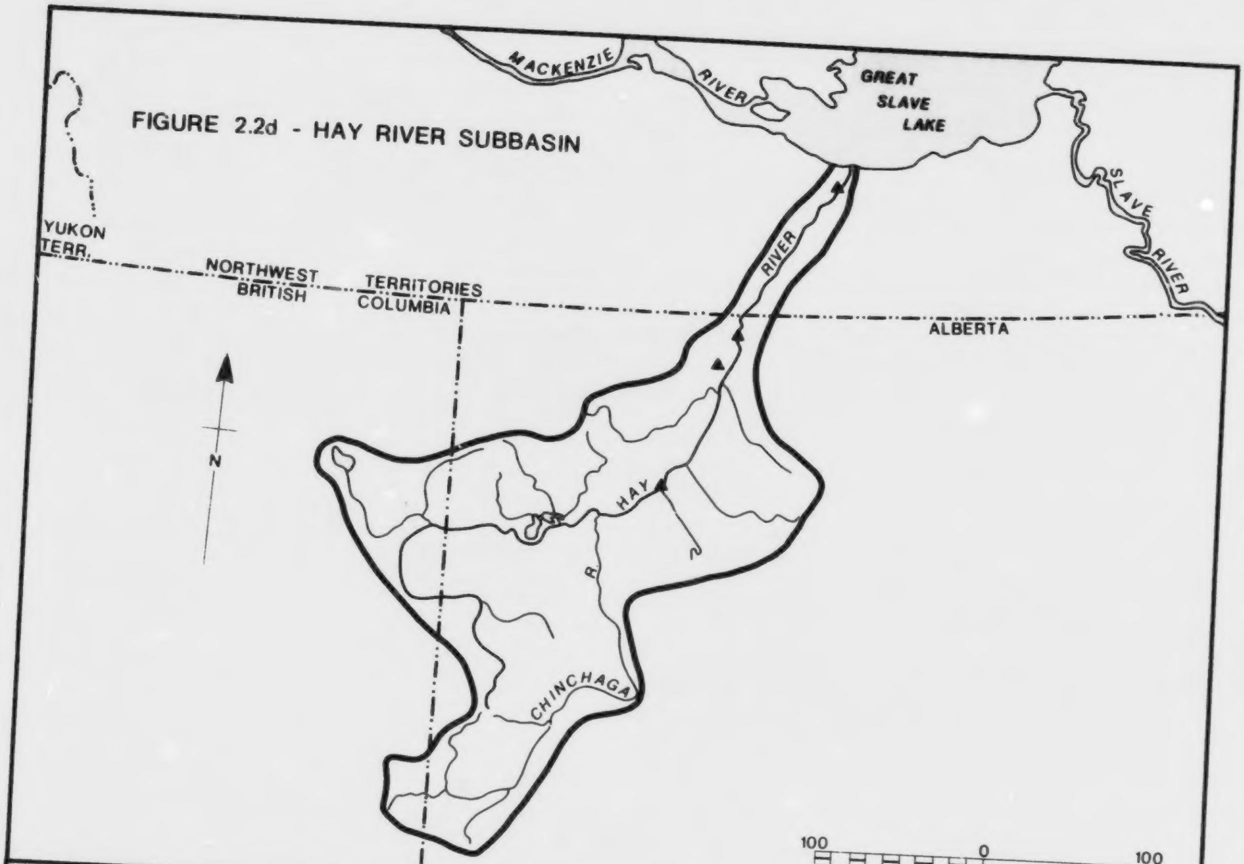


FIGURE 2.2e - GREAT SLAVE LAKE SUBBASIN

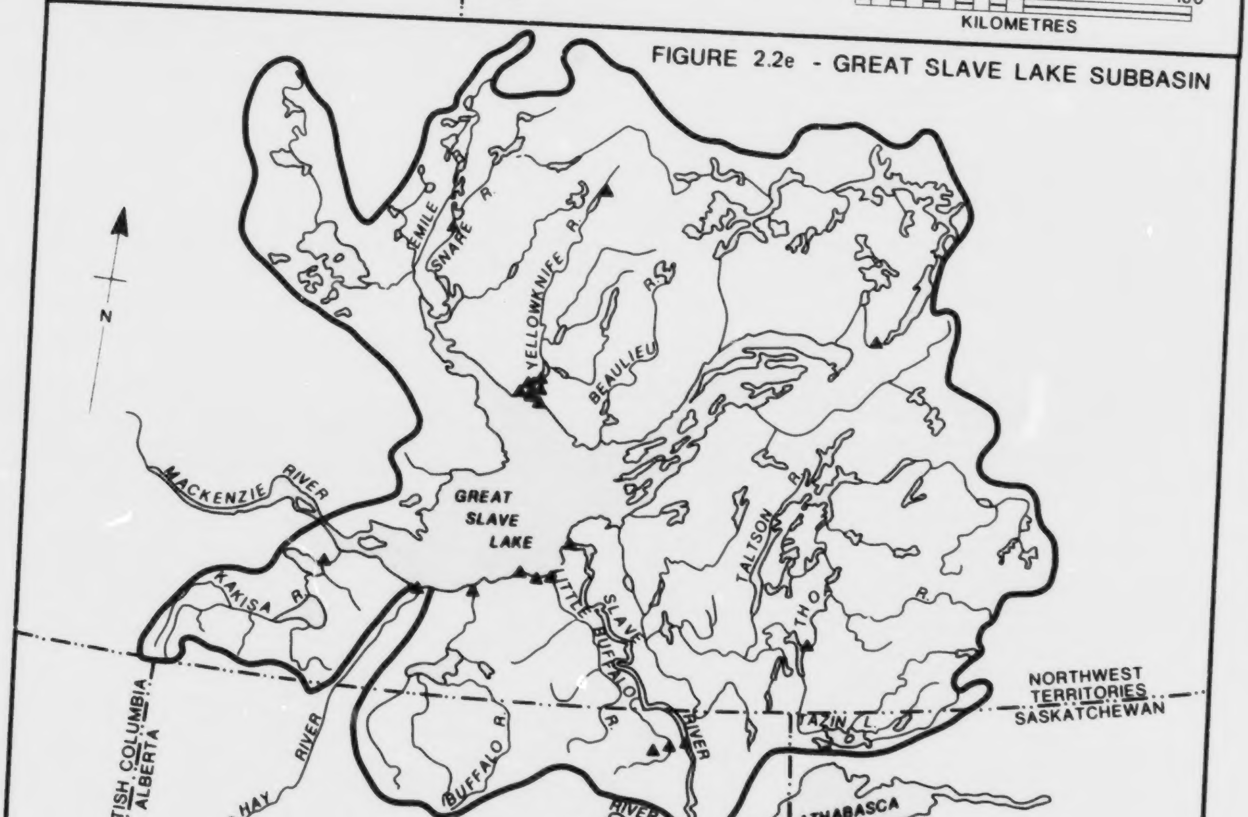


FIGURE 2.2f - GREAT BEAR LAKE SUBBASIN

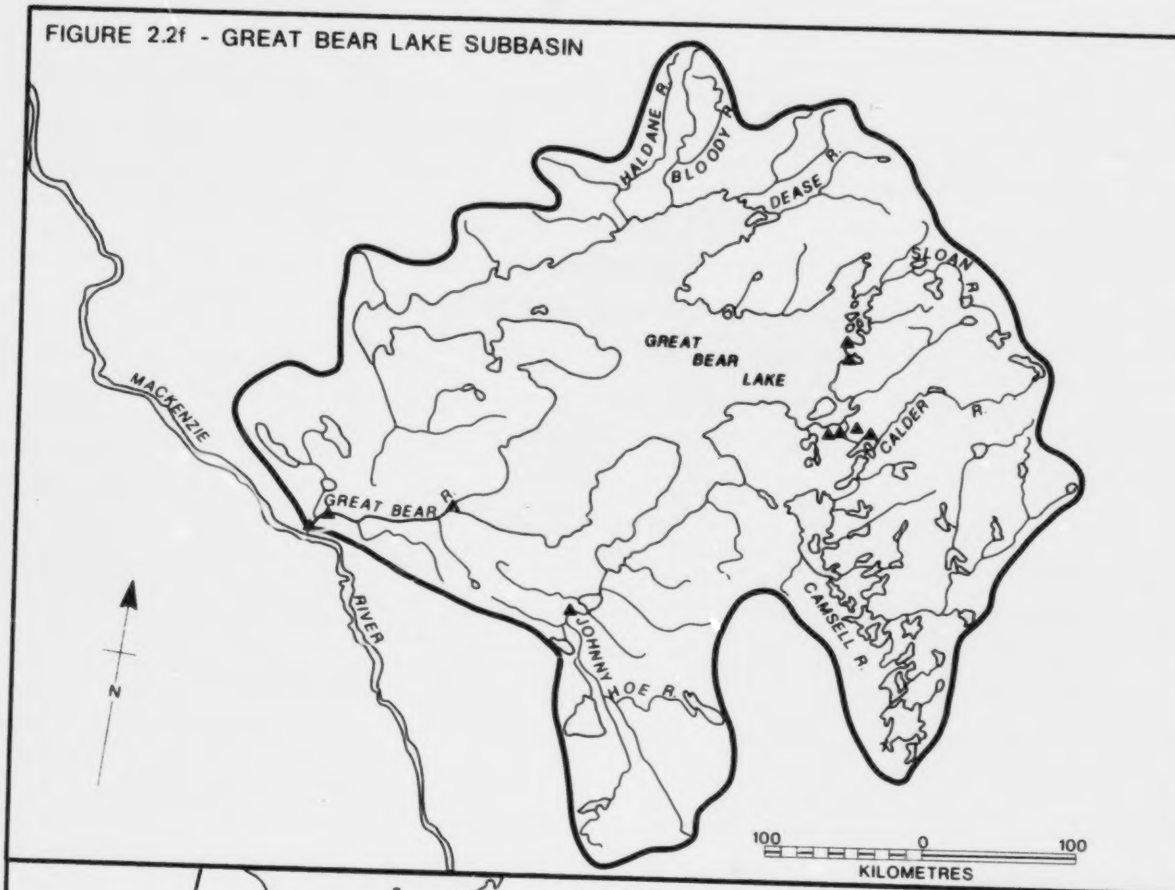
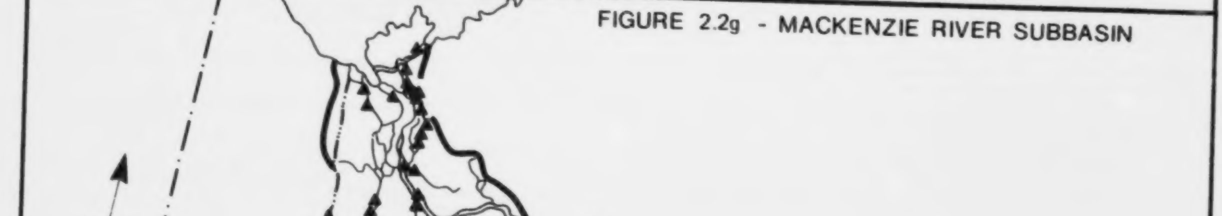


FIGURE 2.2g - MACKENZIE RIVER SUBBASIN



Specific sites in each of the subbasins were chosen for detailed data analysis. These sites are referred to as "selected sites." Selection criteria of the sites included

(1) length of record - sites with the longest, most continuous period of record were given high priority and

(2) location - sites in watershed headwaters, at river mouths, at river confluences, on major tributaries and lake inflows, population centres and areas of present/potential resource development, and sensitive areas.

Selected sites were examined for spatial variations, seasonal trends and interparameter relationships. For many of the evaluations, data for the entire period of record, regardless of data gaps or methodological changes, were considered. At a few sites, seasonal subsets of data were available for certain parameters. The selected sites in each of the subbasins are presented in Table 2.2 and Figure 2.3.

Medians and means were used as characteristic values; they were calculated from all the available results, regardless of variations in sampling frequency or the period of record of individual sites. The choice of a median or mean value depended upon the characteristics of the parameter group and the purpose of the overall value comparison (general, seasonal or spatial). Median values express the probability of the values occurring; they are affected by the number of outlying values but not by the magnitude of the outliers. The median was used in the interpretation for data sets with many similar values, and few values which are greatly different from all other values obtained. The mean was used as a characteristic value for data sets with a high frequency of variability; in these cases, it was desirable to include the magnitude of all values in the calculation of the overall value. Limitations and biases inherent in using all the data include data discontinuities (possibly differing among sites and subbasins), analytical changes, seasonal biases and differing frequencies and times of sample collection over each year at each site or in each subbasin.

Table 2.2 Selected Sites in Mackenzie River Subbasins

Station number	Site description	Rationale
Athabasca River		
00AL07AA0010	Upstream from Sunwapta River	Headwaters
00AL07BE0001	At Athabasca	Present/potential development and population centre
00AL07DA0001	At Fort McMurray	Present/potential development
00AT07DA0053	At Bitumount	Mouth, close to sensitive area
00SA07LC0001	Fond du Lac River	Sensitive area, tributary to Lake Athabasca
Peace River		
00BC07EF0001	Outlet of W.A.C. Bennett Dam (at Hwy. 29)	Headwaters
00AT07FD0001	At Dunvegan	Downstream from development
00AL07KC0001	At Peace Point	Mouth, upstream from sensitive area
00AL07GJ0001	Smoky River at Watino	Tributary of Peace River
Liard River		
00YT10AA0001	Upstream from Dease River	Headwaters
00NW10ED0001	At Fort Liard	Present/potential development
00NW10ED0002	Upstream from Fort Simpson	Mouth
00NW10EC0001	South Nahanni River	Tributary of Liard River
Hay River		
00NW07OB0001	Hay River	Mouth
Great Bear Lake		
00NW10JC0001	Outlet of Great Bear Lake	Tributary of Mackenzie River, upstream from sensitive areas
00NW10JA0001	Camsell River	Major inflow to Great Bear Lake
Great Slave Lake		
00AL07NB0001	Slave River at Fitzgerald	Major inflow to Great Slave Lake
00NW07RD0001	Lockhart River downstream from Artillery Lake	Inflow, sensitive area
01NW07SB0003	Yellowknife Bay	Present/potential development
Mackenzie River		
00NW10FB0001	At Fort Providence	Headwaters
00NW10HC0001	Near Wrigley	Present/potential development
00NW10KA0001	Near Norman Wells	Present/potential development
00NW10LA0003	Upstream from Arctic Red River	Mouth, upstream from sensitive area

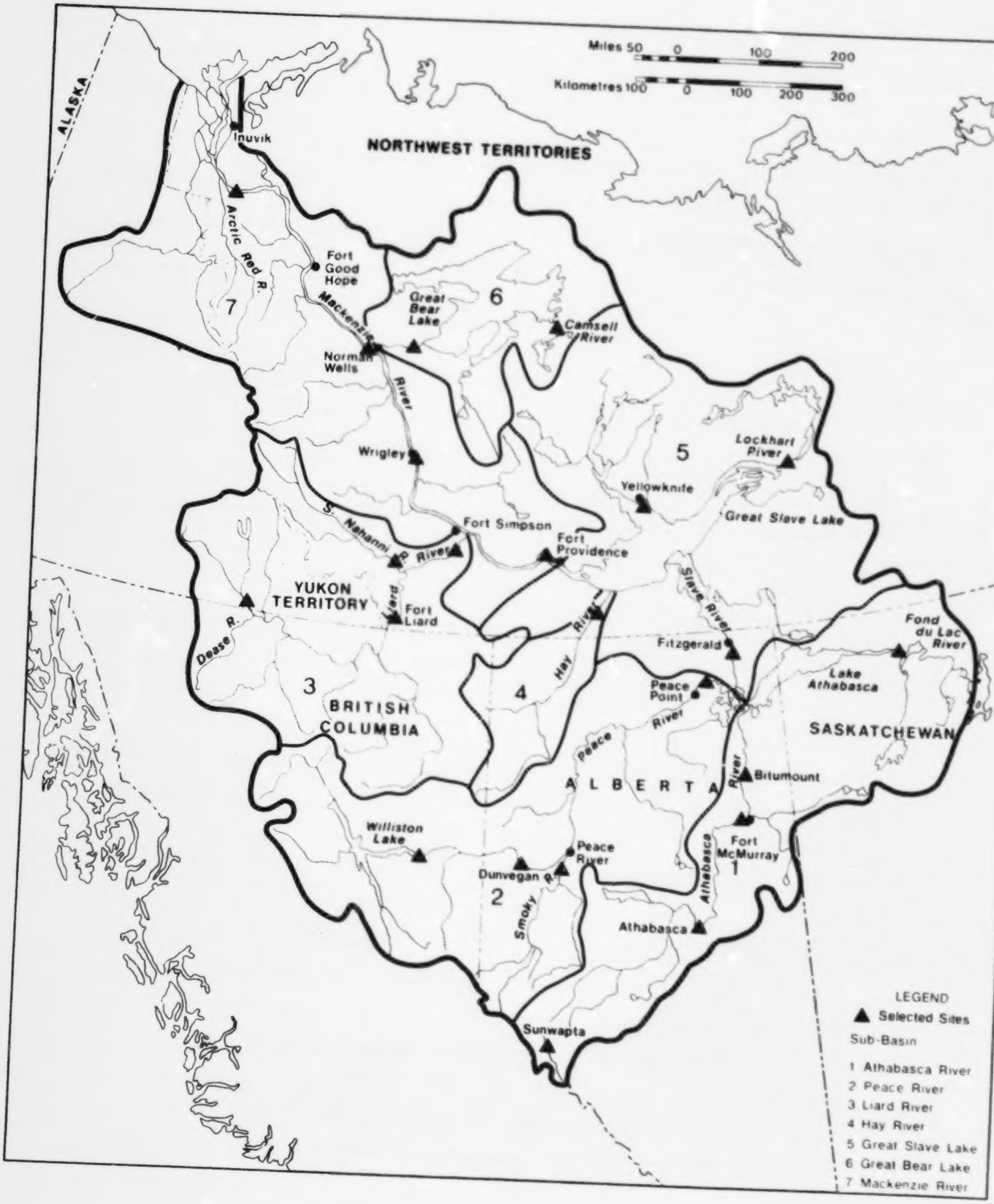


Figure 2.3 Selected sites for water quality data interpretation in Mackenzie River subbasins.

Water Quality Parameters

Water quality parameters are discussed under the following categories: physical parameters, major ions, nutrients, metals and organic parameters.

For each of these categories, variations in the concentrations of water quality parameters between the subbasins, influences of the tributaries on the mainstem of the Mackenzie River, seasonal variations and relationships among the parameters are investigated. Attempts are made to relate these variations to sources and where possible, to in-stream biological and chemical interactions. The ecological significance of the parameter concentrations is briefly discussed.

3.1 Physical Parameters

3.1.1 Introduction

The physical parameters play important roles in determining the quality of rivers and lakes and, ultimately, the structure of the biological community. Turbidity, apparent colour, total dissolved solids (TDS), specific conductivity and pH are discussed in this section.

Turbidity is a measure of suspended particles, mineral and organic, present in water. These solids originate from in-stream bank and bed erosion, surface runoff, algal populations and anthropogenic sources. Apparent colour is a measure of dissolved and suspended mineral and organic material. Colour units of less than ten indicate essentially clear water; values over 200 units are characteristic of swamp and bog water and of dystrophic lakes. High colour and turbidity can directly reduce photosynthesis and interfere with the efficiency of sight-feeding fish. The parameters affect the attenuation and intensity of various light wavelengths, thereby affecting zooplankton migrations. The effects of interference with light transmission on higher organisms are secondary; invertebrate spawning, larval success and timing of the spring phytoplankton bloom are affected.

Total dissolved solids (TDS) is a measure of dissolved substances in water. High concentrations of TDS may impair the ability of organisms to regulate the intake and elimination of water without causing an imbalance in the concentration of body fluids. The TDS concentrations are important in determining the species composition of aquatic systems. Specific conductivity expresses the ability of water to conduct an electrical current; it is a function of the concentration of dissolved substances and temperature.

The pH is defined as the negative logarithm of the hydrogen ion concentration. Values indicate the potential for chemical reaction between water, rocks and soils. The pH affects the transformation processes between various forms of nutrients and metals and therefore determines the availability and toxicity of these elements for aquatic life.

3.1.2 Median Values for the Subbasins

Median values were chosen to express an overall value for the physical parameters in rivers and lakes of each subbasin (Table 3.1). As spurious values are characteristic of physical parameter data, the median was preferred over the arithmetic mean, as the latter can be strongly biased by the presence of isolated values that are greatly different from all other values obtained. To complement the median, the minimum, maximum and main percentile values were also calculated. These values for the selected sites are in Table C-1, Appendix C.

3.1.2.1 Rivers

Examination of subbasin medians (Fig. 3.1) for rivers reveals that subbasins in the Western Cordillera have similar physical characteristics and they are different from the subbasins in the Precambrian Shield. The Athabasca, Peace and Liard rivers originate in the Rocky Mountains and flow largely through the Interior Plain. The

Table 3.1 Median Values of Physical Parameters for Mackenzie River Subbasins

Subbasin	Turbidity (NTU)	Apparent colour (rel. units)	TDS (mg L^{-1})	Specific conductivity ($\mu S\ cm^{-1}$)
Rivers				
Athabasca	10	25	135	265
Peace	16	25	130	231
Liard	6.2	10	131	253
Hay	13	130	216	383
Great Bear	1.8	5	76	143
Great Slave	38	30	119	224
Mackenzie	7.0	15	131	244
Lakes				
Athabasca	2.3	10	65	139
Peace	-	-	-	143
Great Bear	1.0	5	80	160
Great Slave	2.2	8	48	82

rivers of the subbasins have relatively high turbidities, as they are underlain by easily erodible sandstones and shales.

The Hay River flows entirely within the Interior Plain. The river has levels of TDS and specific conductivity up to twice the concentrations of subbasins in the Western Cordillera. Colour values are almost sixfold greater, reflecting the abundant muskeg, high in organic humic and fulvic acids that drain into the river throughout this lowland basin.

The northeastern portion of the Athabasca subbasin and significant areas of the Great Slave and Great Bear watersheds are in the Shield region. In general, these Shield waters have relatively low turbidity and colour, and relatively low values of TDS and conductivity. These physical characteristics reflect the erosion-resistant, igneous Shield rock contributing low levels of dissolved constituents. Water quality monitoring sites in the Great Bear subbasin, located almost exclusively in the Shield, show these characteristics. However, the

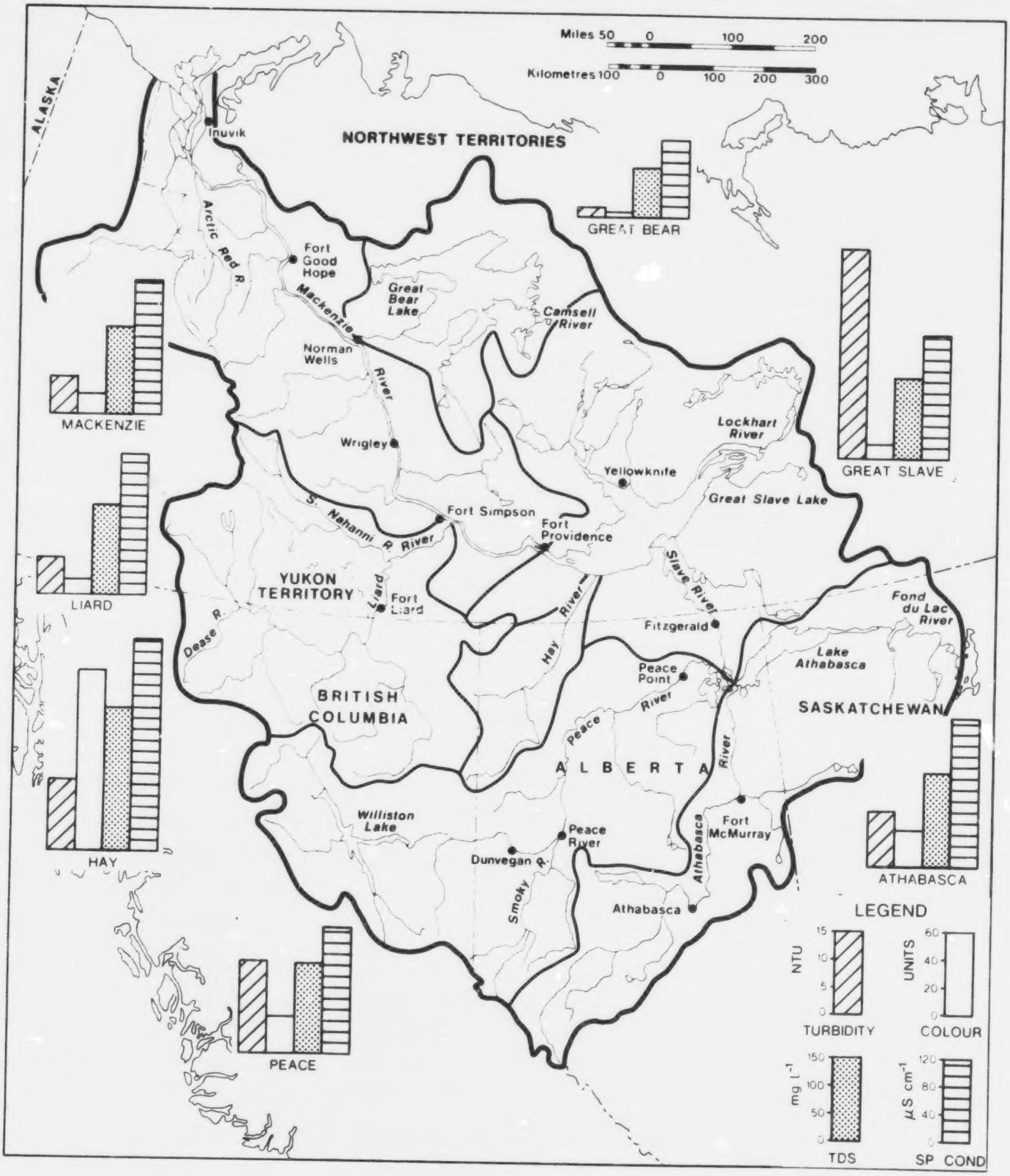


Figure 3.1 Median values for physical parameters for rivers of the Mackenzie River subbasins.

Athabasca and Great Slave subbasins do not indicate these features, as most of the the drainage area is located in the Interior Plain.

The Mackenzie subbasin, although flowing through variable lithology and receiving drainage waters from each of the subbasins, has similar physical characteristics to the Athabasca, Peace and Liard systems. This reflects the predominant discharge contributions from these rivers to the Mackenzie River.

3.1.2.2 Lakes

Water quality data for lakes are available for the Athabasca, Peace, Great Slave, and Great Bear subbasins (Fig. 3.2). Physical characteristics are notably lower than those for rivers. This reflects deposition of suspended material in the lake, dilution of inputs of dissolved constituents, and the absence of extreme values due to more stable conditions. The exceptions are TDS and specific conductivity in the Great Bear Lake subbasin where lake values are marginally higher than those for rivers.

3.1.3 Spatial Variations

Physical data for selected sites in the Athabasca, Peace and Mackenzie subbasins permit a limited assessment of downstream trends. The trends reflect variations in lithology, relief and discharge, as well as contributions from tributary and groundwater sources of dissolved and suspended material. The downstream trend assessment assumes that between site differences reflect changes representative of the continuous river system and not merely different local effects.

Turbidity at the glacial headwaters (upstream from Sunwapta) of the Athabasca River (Fig. 3.3) shows minimal change at Athabasca, then a significant increase at Fort McMurray and Bitumount (8.0-7.0-15-22 NTU), reflecting accumulation of suspended matter from erodible materials in the Western Cordillera. Colour units increase from Sunwapta to Fort McMurray (5-20-30 units) due to the increase in organic content of waters

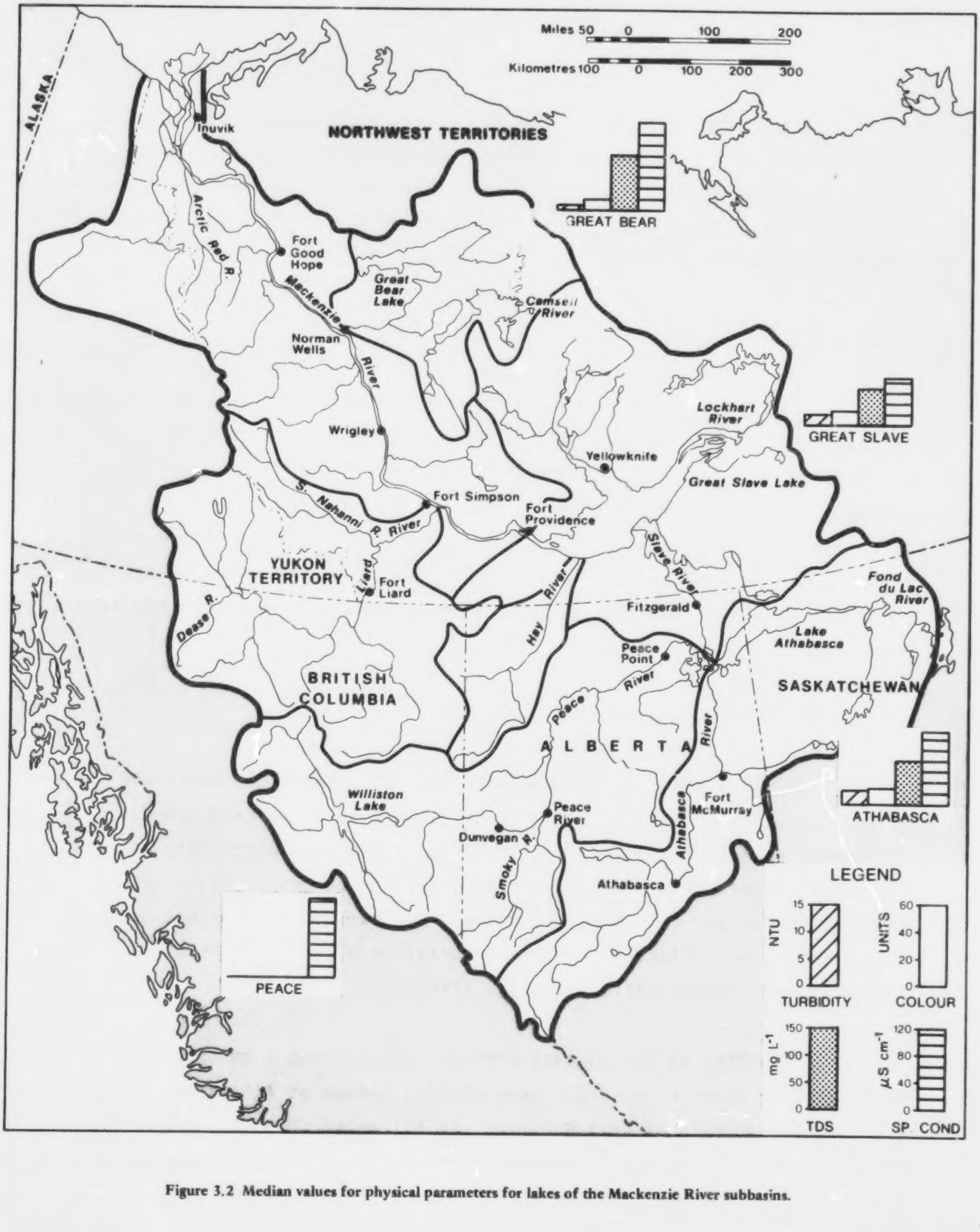


Figure 3.2 Median values for physical parameters for lakes of the Mackenzie River subbasins.

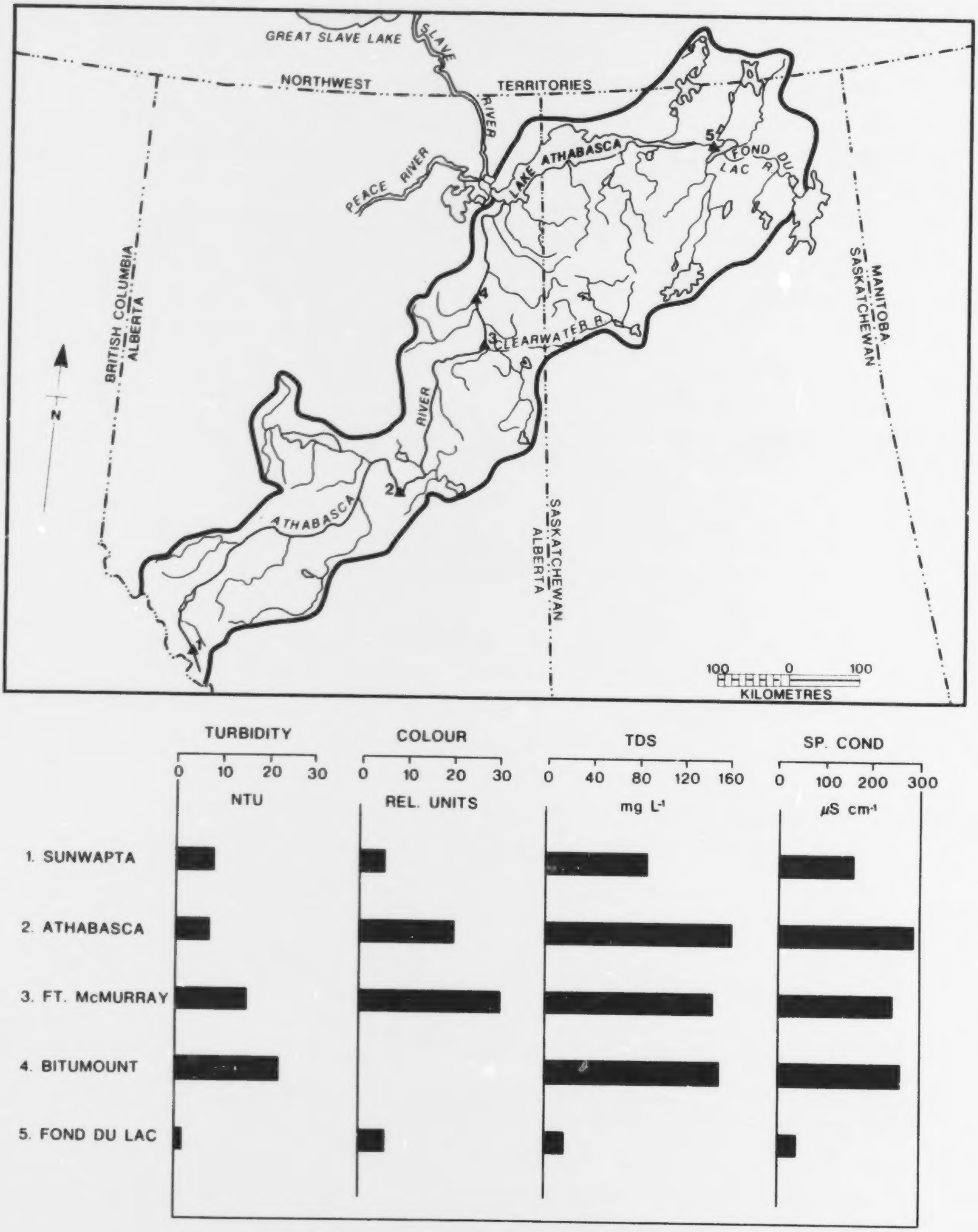


Figure 3.3 Spatial variation of physical parameters (medians) at selected sites in the Athabasca River subbasin.

flowing in the Interior Plain and due to the increase in turbidity. As expected, TDS and specific conductivity have parallel trends; values increase from Sunwapta to Athabasca, and then decline slightly at Fort McMurray and Bitumount. The latter decline may reflect dilution effects of the Clearwater River.

Levels of turbidity (1.9-10-17 NTU), colour (10-13-30 units), TDS (98-110-131 mg L^{-1}) and specific conductivity (185-225-240 µS cm^{-1}) increase gradually in the Peace subbasin from the Bennett Dam outlet to the river mouth (Fig. 3.4) due to the additive effect of dissolved and suspended substances. The Smoky River contributes concentrations of all constituents that are notably elevated (35 NTU, 30 units, 151 mg L^{-1}, 282 µS cm^{-1}) in comparison with those in the mainstem river water.

All physical descriptors of the Mackenzie subbasin considered here increase from Fort Providence to Wrigley, decline slightly at Norman Wells, then rise again upstream from the confluence with the Arctic Red River (Fig. 3.5). Turbidity changes more noticeably among sites than do the other parameters. This trend reflects the relatively clear water draining Great Slave Lake, inputs from the turbid Liard River between Fort Providence and Wrigley, the input of essentially lake water to the Mackenzie River from Great Bear River upstream from Norman Wells, and the accumulation of dissolved and suspended material from numerous tributaries and groundwater sources along the main river channel. The turbidity trend highlights the important role of the Great Slave and Great Bear lakes as sediment settling basins and sources of sediment-free water in the Mackenzie drainage network.

3.1.4 Seasonal Variations and Interparameter Relationships

Fluctuations in concentrations of the physical parameters occur over the hydrologic year. Seasonality of turbidity, colour, TDS and pH and their relationship with discharge are shown in Figures 3.6 to 3.14. Few sites have sufficient data to show seasonality; the Athabasca River at Athabasca site (00AL07BE0001) was chosen to illustrate seasonal variations because of the relative continuity of the available data. All years of record were included in the evaluation.

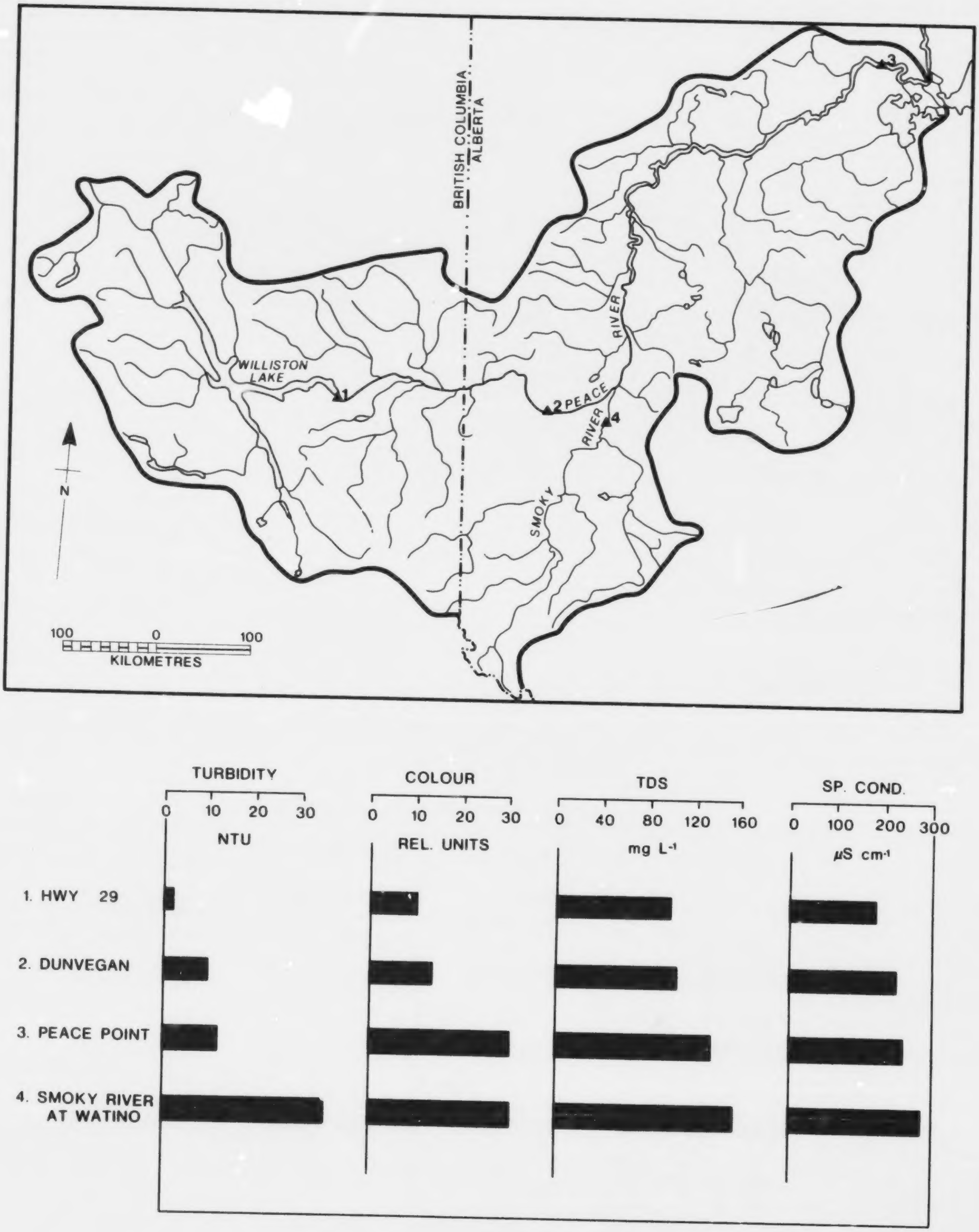


Figure 3.4 Spatial variation of physical parameters (medians) at selected sites in the Peace River subbasin.

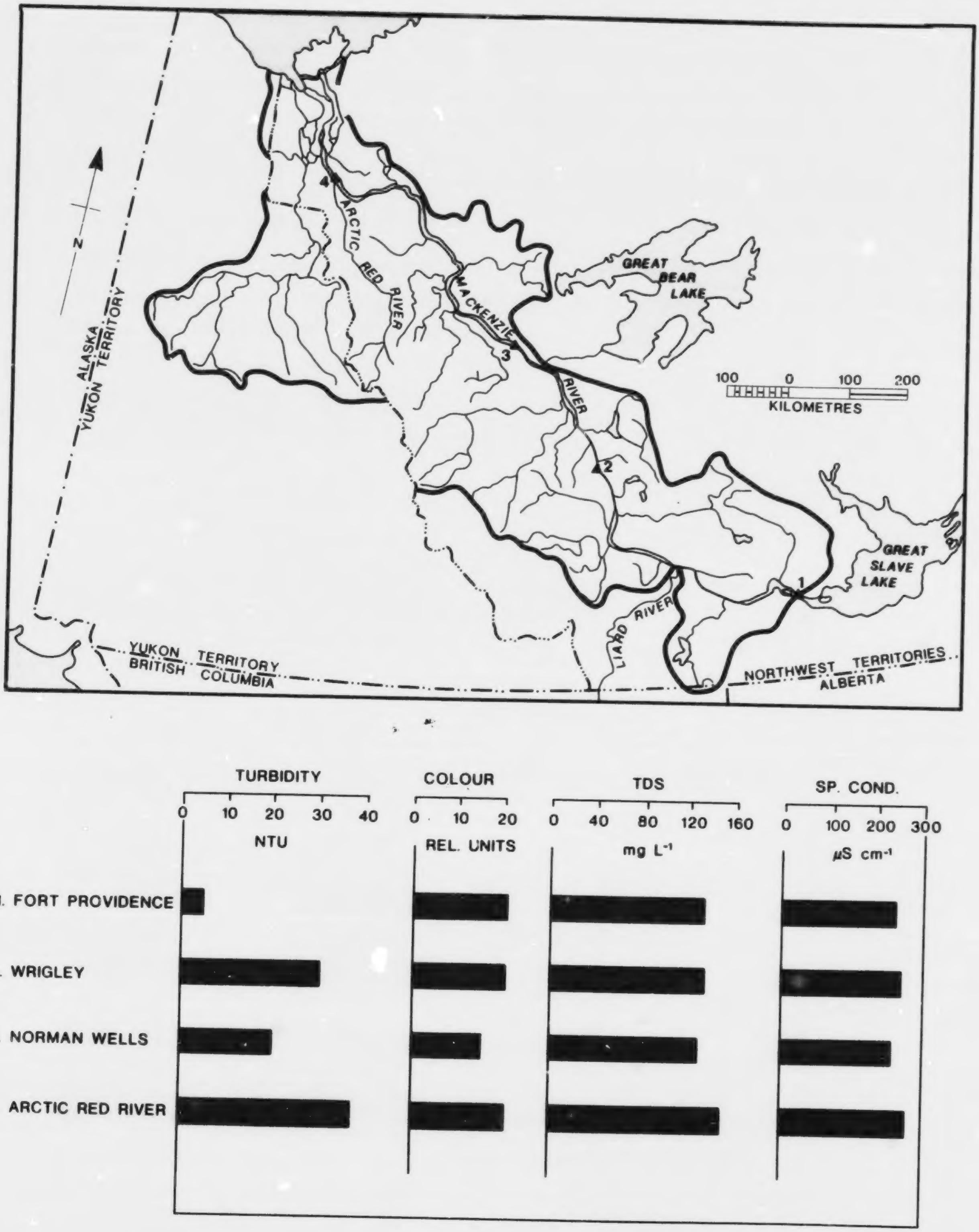


Figure 3.5 Spatial variation of physical parameters (medians) at selected sites in the Mackenzie River subbasin.

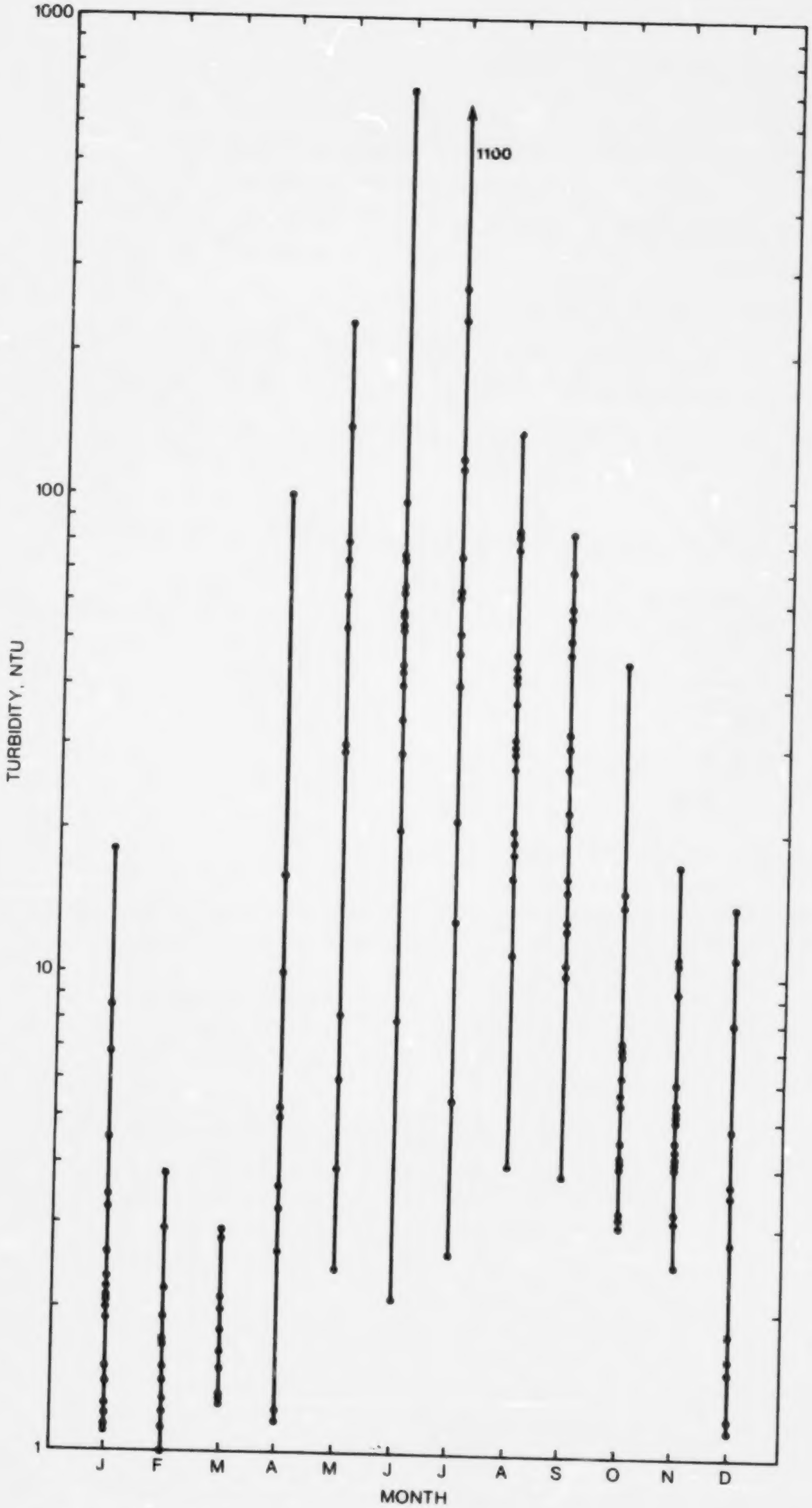


Figure 3.6 Seasonal variation of turbidity at Athabasca River at Athabasca (00AL07BE0001).

Turbidity values are low (<10 NTU) over the winter period (November-March; Figure 3.6) and increase by an order of magnitude (100 NTU) in April. Values over the summer months are the highest for the year and display large fluctuations. The highest turbidity values are recorded in July (1100 NTU).

The trend of colour (Fig. 3.7) over the year is similar to that of turbidity. Values are low in winter (<35 units) and up to an order of magnitude higher during the summer period. The highest values (200 units) and the greatest range of values for a single month occur in April.

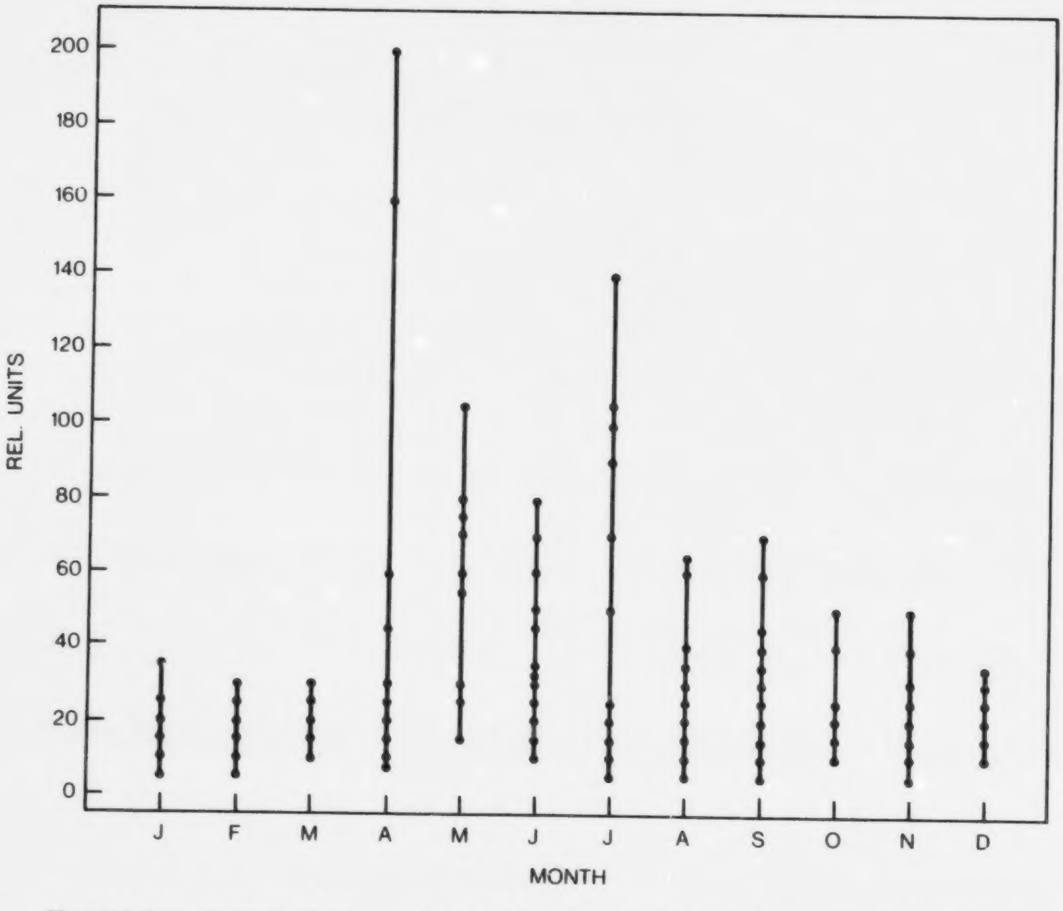


Figure 3.7 Seasonal variation of apparent colour at Athabasca River at Athabasca (00AL07BE0001), 1960–1979.

The patterns of turbidity and colour are directly related to the hydrologic regime (Fig. 3.8). Discharge is low from January-March, increases abruptly in April, peaks in July, then gradually declines for the rest of the year. Spring melt and high flows mobilize suspended material by erosion and overland flow processes; these account for the parallel trends in discharge and turbidity. The colour increase in April reflects mineral material in suspension, whereas elevated summer values are likely due to the presence of mineral as well as dissolved organic matter from surface runoff, bog drainage and in-stream sources. Local rainstorm events may cause intraseasonal variations in turbidity and colour.

Seasonality of TDS displays an inverse pattern to that of turbidity and colour (Fig. 3.9). Annual high TDS values occur from January-March (200-290 mg L^{-1}). April values fall to an annual low

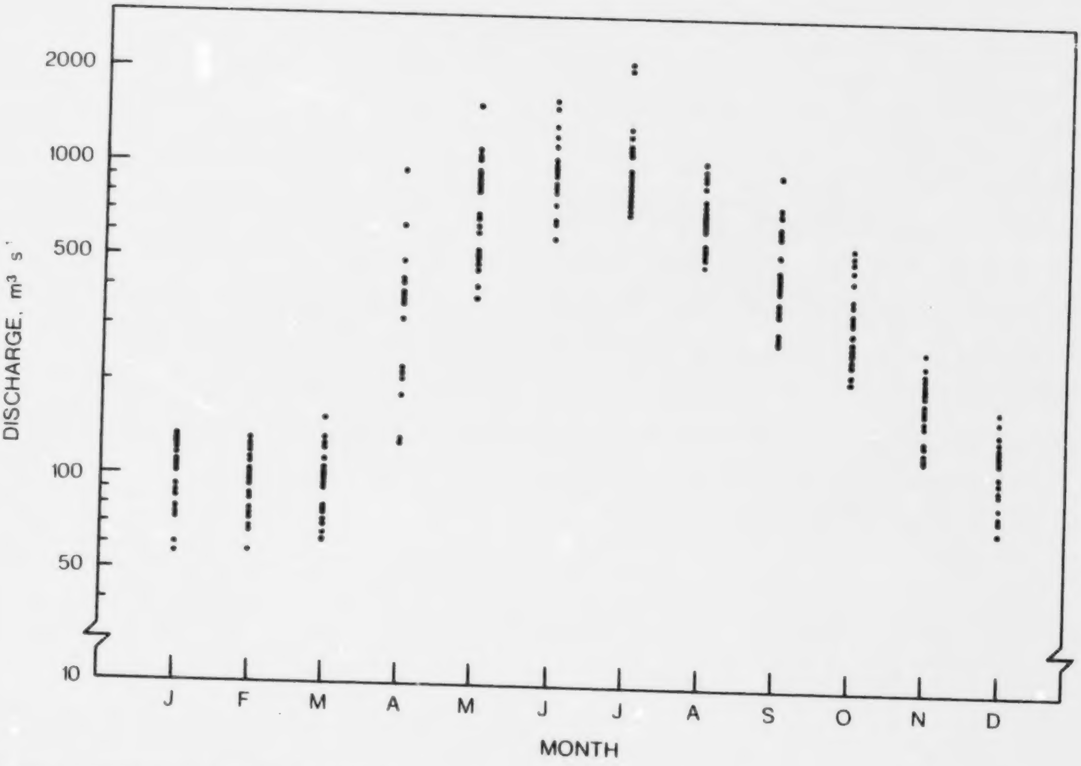


Figure 3.8 Mean monthly discharge at Athabasca River at Athabasca (00AL07BE0001), 1960-1979. Water Survey of Canada.

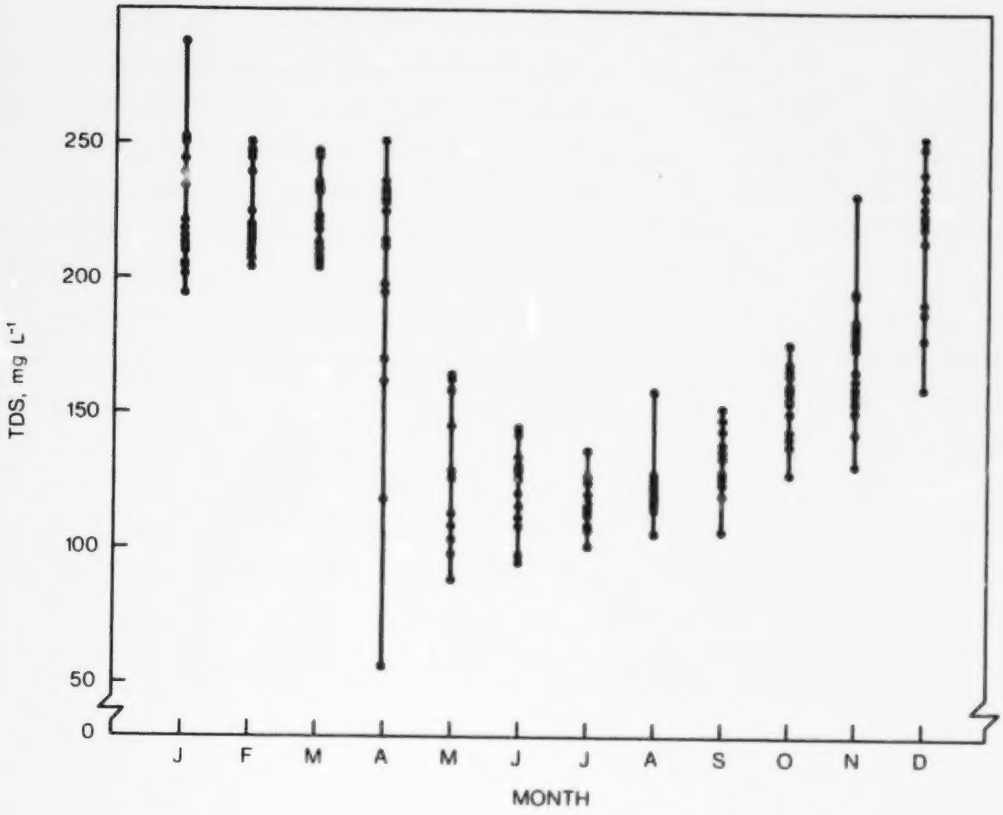


Figure 3.9 Seasonal variation of total dissolved solids at Athabasca River at Athabasca (00AL07BE0001), 1960–1979.

(~100 mg L^{-1}) and are highly variable. The TDS content rises steadily over the summer and fall as flows decline. Spring concentrations of dissolved substances are diluted by increases in discharge. The inverse relationship between TDS and discharge is shown in Figure 3.10. The strong positive association between TDS and specific conductivity is shown in Figure 3.11. The behaviour of dissolved substances is discussed more fully in section 3.2.

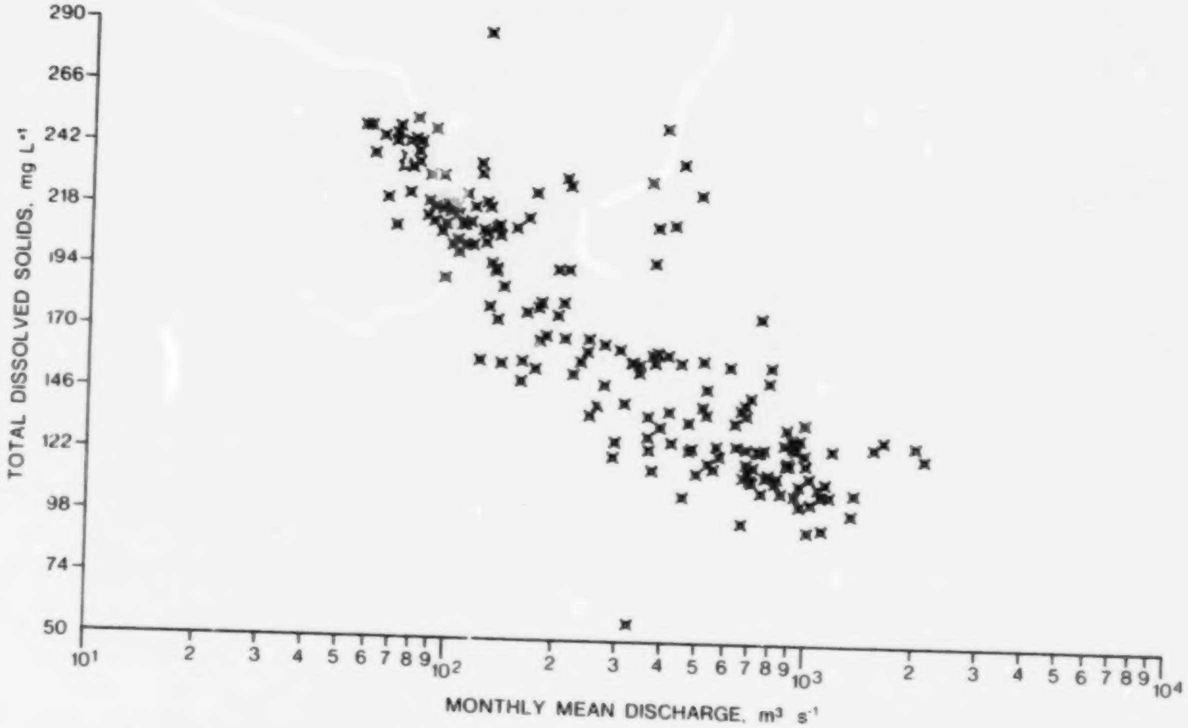


Figure 3.10 Relationship between discharge and total dissolved solids, 1960–1979. Athabasca River at Athabasca (00AL07BE0001).

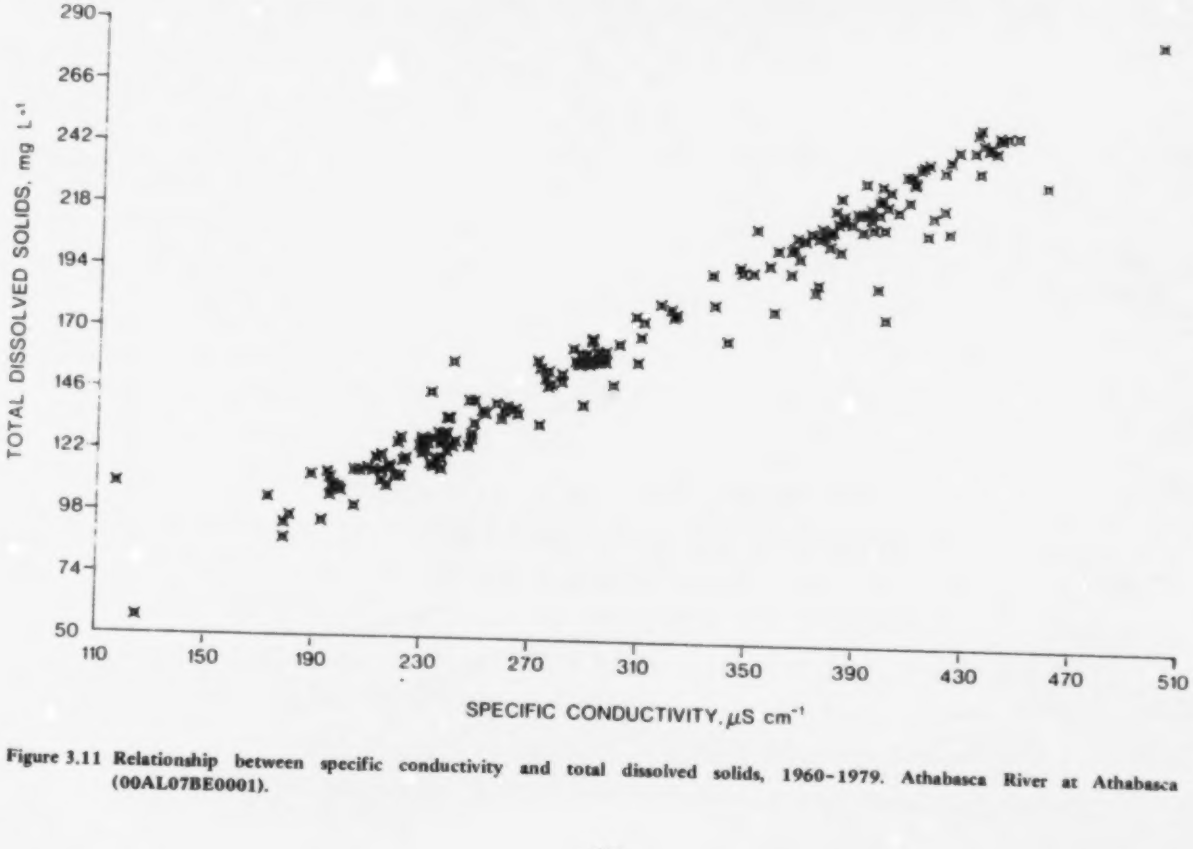


Figure 3.11 Relationship between specific conductivity and total dissolved solids, 1960–1979. Athabasca River at Athabasca (00AL07BE0001).

Values of pH indicate little change over the year and over time (Figs. 3.12 and 3.13). Discharge and pH do not appear to be related (Fig. 3.14).

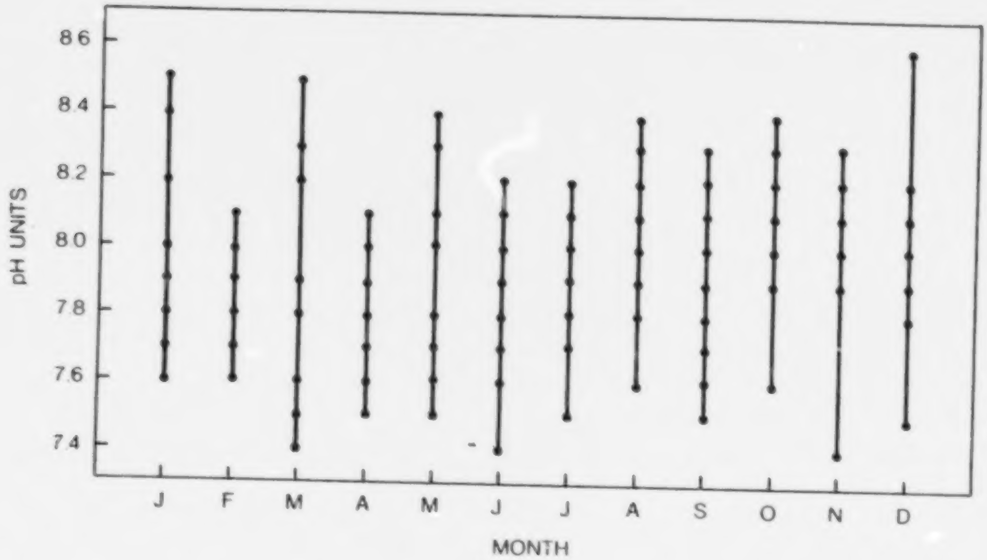


Figure 3.12 Seasonal variation of pH at Athabasca River at Athabasca (00AL07BE0001), 1960–1979.

The seasonal relationships of physical parameters at sites in the Peace, Liard and Mackenzie subbasins may be similar to those noted for the Athabasca River at Athabasca. This is suggested by relationships between the parameters and discharge and the similarity of the hydrographs (Fig. 3.15).

Parameters in rivers and at lake sites in the Shield area show different seasonal behaviour. Limited data, however, restrict interpretation in these areas. Relatively low values of TDS (<30 mg L^{-1}) at Yellowknife Bay (Great Slave Lake) predominate in the winter; the highest values occur in spring (up to 1700 mg L^{-1}) and summer. High discharges from the Yellowknife River, containing relatively higher concentrations of TDS than those present in the Bay, cause the spring concentrations; the higher summer values may reflect input from rivers draining the Shield area.

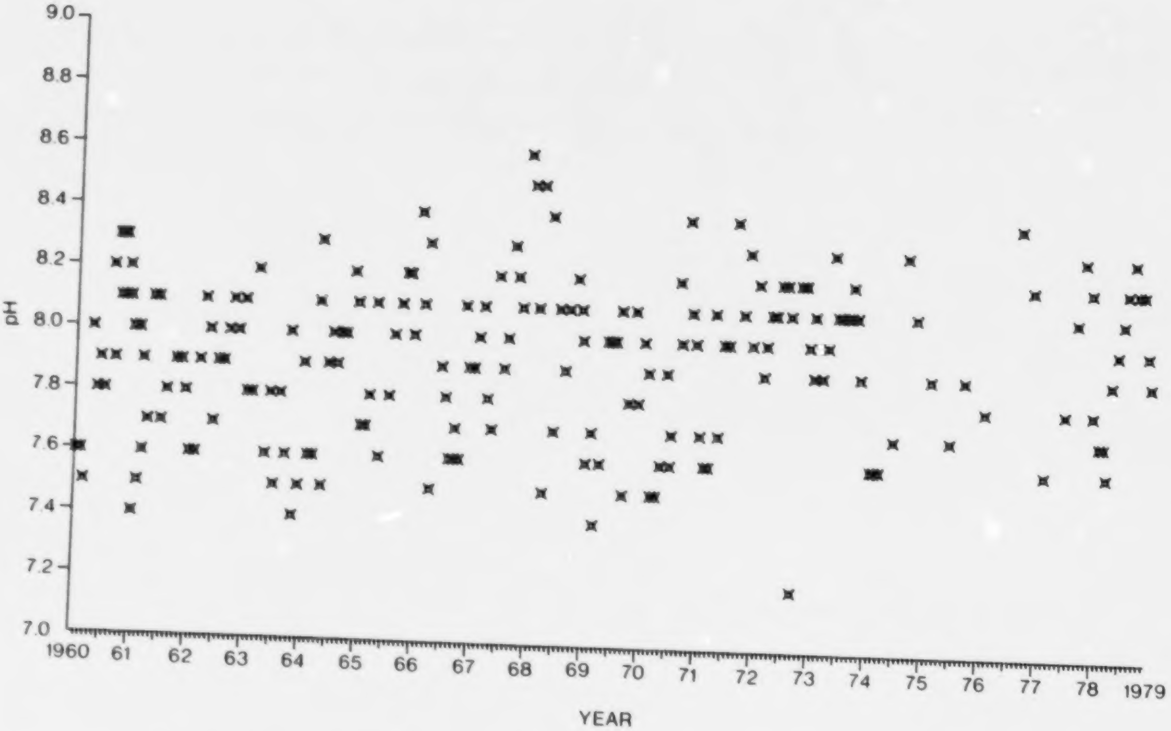


Figure 3.13 Variation of pH over time, 1960–1979. Athabasca River at Athabasca (00AL07BE0001).

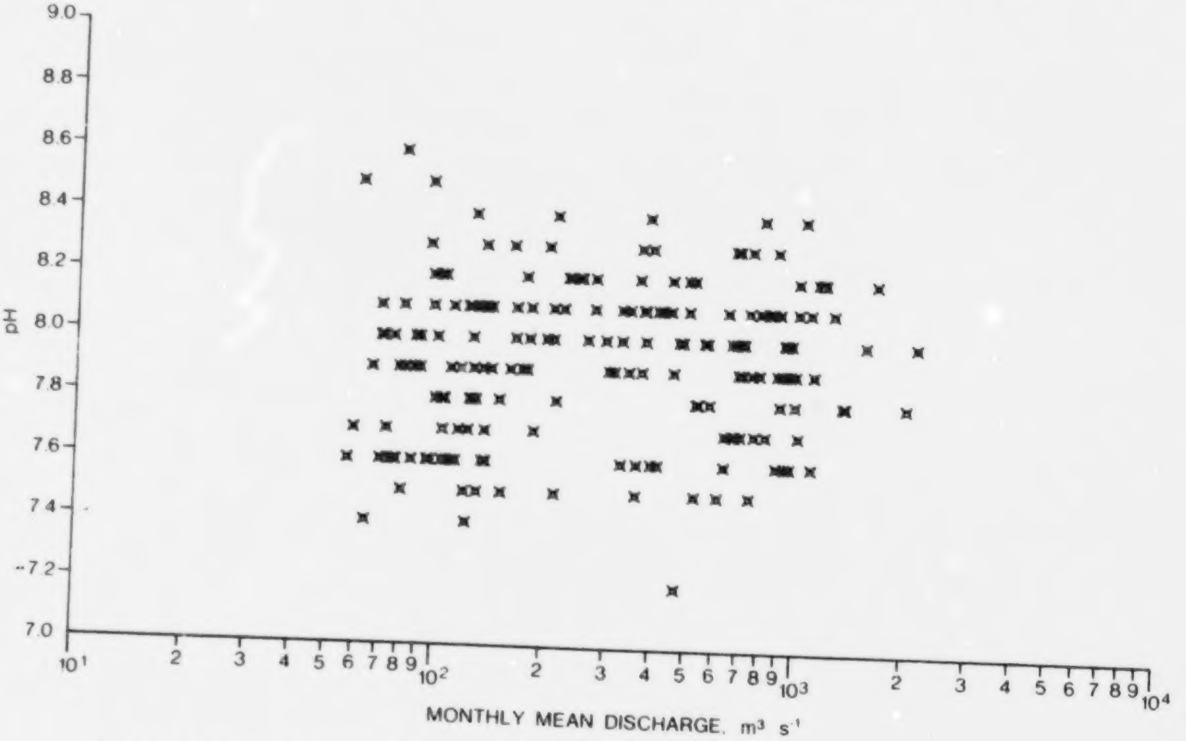


Figure 3.14 Relationship between discharge and pH, 1960–1979. Athabasca River at Athabasca (00AL07BE0001).

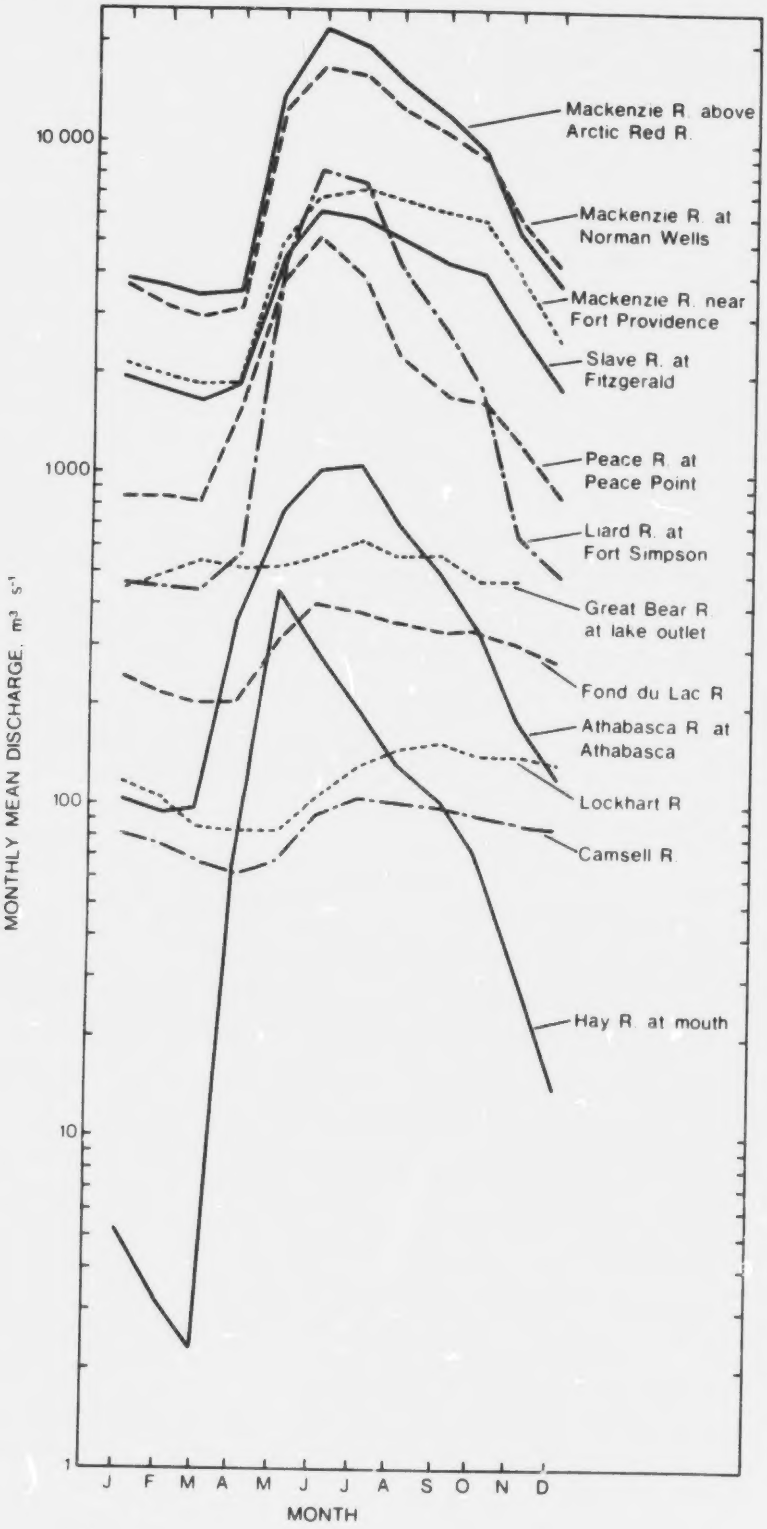


Figure 3.15 Monthly mean discharge (1960-1979) for selected sites in the Mackenzie River basin.

The trend of TDS in the Camsell River is similar to the trend at Athabasca, but the variations for each month and between each season are significantly less. The dampened trend reflects the stable flow regime of a river draining a lake, as well as the lesser temporal range of dissolved constituent composition of Shield waters.

Changes in the concentrations of turbidity, specific conductivity, TDS and pH over time were investigated (Figs. 3.13, 3.16, 3.17, 3.18). Variations occur over the period of record but no net changes are apparent.

3.1.5 Comparison of Subbasin and Selected Site Medians

The similarity of values for physical parameters at the selected sites to the aggregate value for each subbasin was evaluated by comparing the selected site (Table C-1, Appendix C) and the subbasin (Table 3.1)

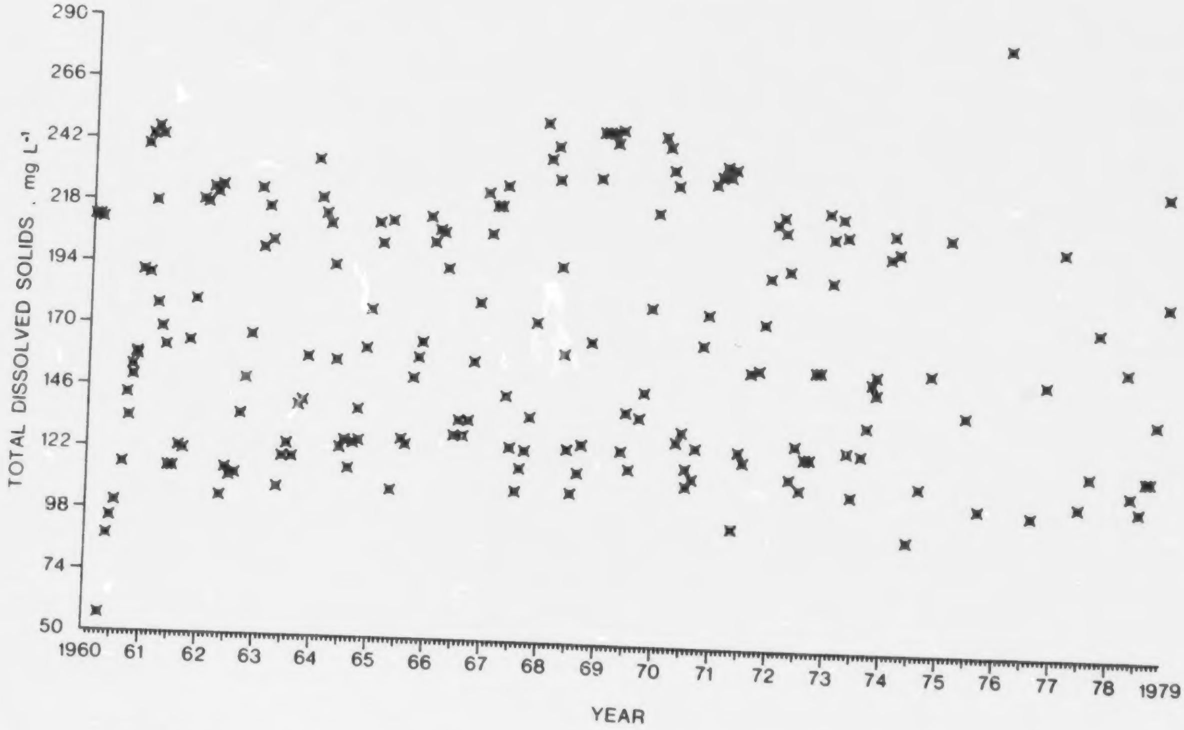


Figure 3.16 Variation of total dissolved solids over time, 1960–1979. Athabasca River at Athabasca (00AL07BE0001).

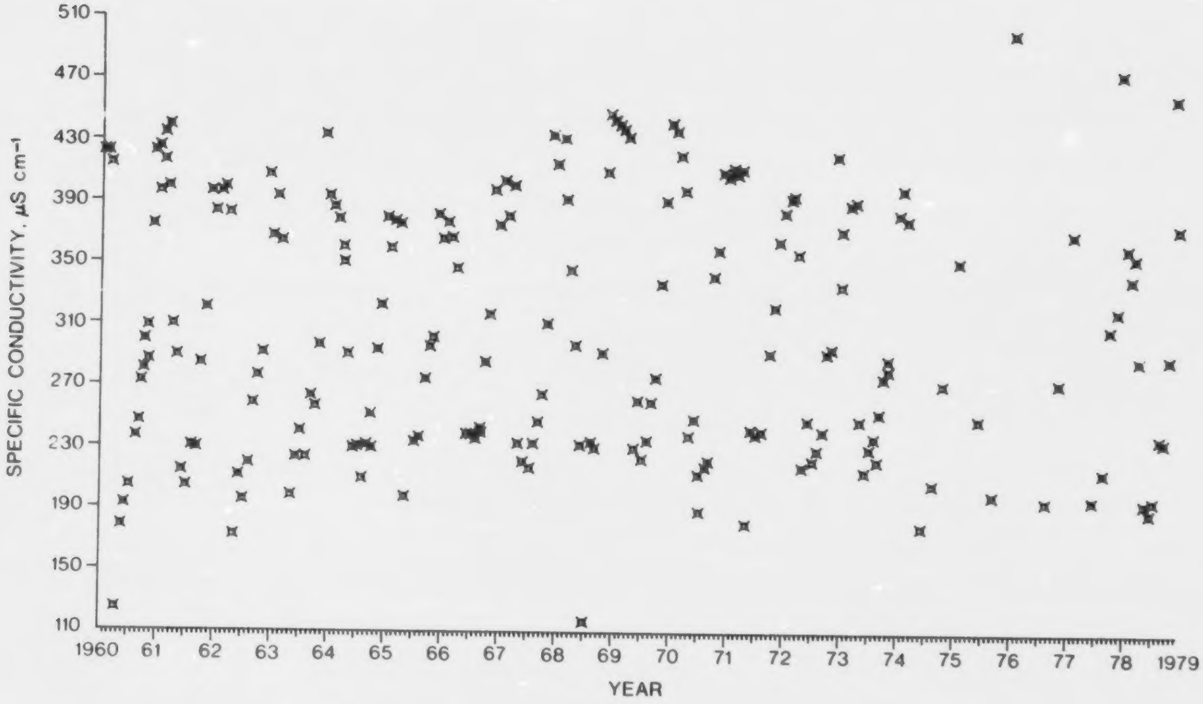


Figure 3.17 Variation of specific conductivity over time, 1960-1979. Athabasca River at Athabasca (00AL07BE0001).

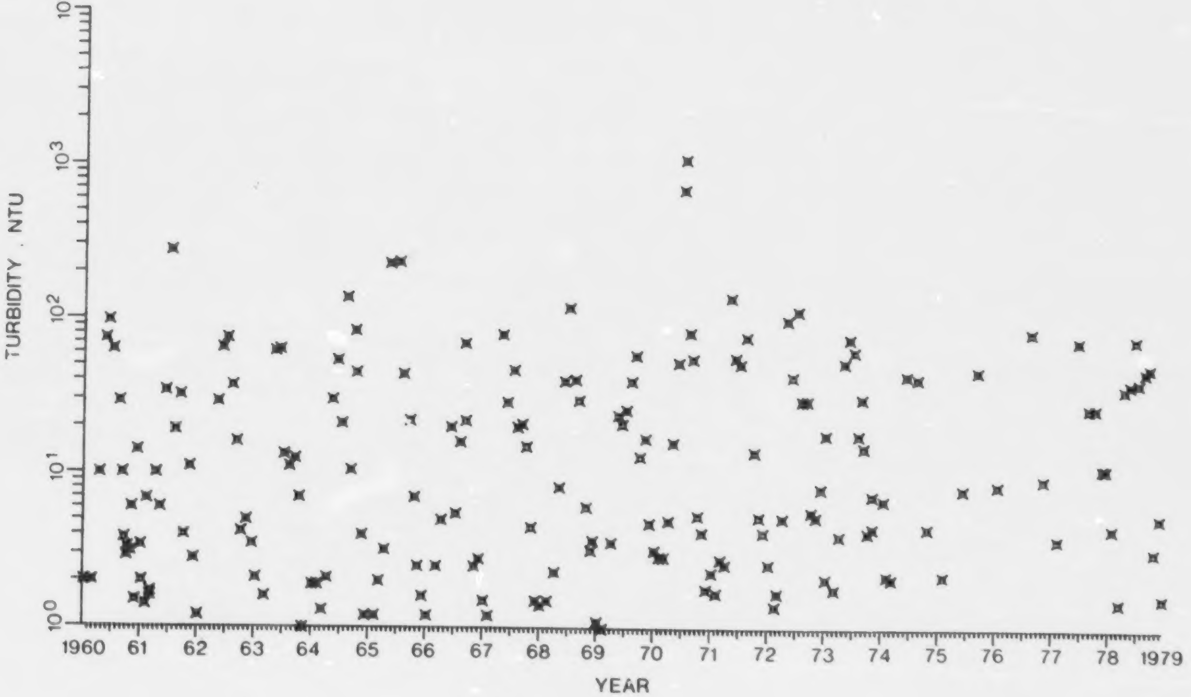


Figure 3.18 Variation of turbidity over time, 1960-1979. Athabasca River at Athabasca (00AL07BE0001).

medians. Table 3.2 subjectively expresses the closeness (within 15% or 25%) of each site parameter median to the subbasin parameter median. The comparison is an estimate of the representativeness of selected site

Table 3.2 Comparison of Subbasin and Selected Site Medians - Physical Parameters

Subbasin, selected site	Turbidity	Colour	TDS	Specific conductivity
Athabasca				
Upstream from Sunwapta	✓			
At Athabasca	✓	✓		✓
At Fort McMurray	✓		✓	✓
At Bitumount		✓	✓	✓
Fond du Lac River				
Peace				
At HWY 29				
At Dunvegan	(✓)		✓	✓
At Peace Point	✓	✓	✓	✓
Smoky River at Watino		✓	✓	✓
Liard				
Upstream from Dease River		✓		
At Fort Liard	✓			
Upstream from Fort Simpson			✓	✓
South Nahanni River		✓	(✓)	
Hay				
Hay River at mouth	✓	✓	(✓)	✓
Great Bear				
Great Bear Lake outlet	✓	✓	✓	
Camsell River	✓	✓	(✓)	
Great Slave				
Slave River at Fitzgerald	✓	✓	✓	✓
Lockhart River				
Yellowknife Bay				
Mackenzie				
At Fort Providence	✓	✓	✓	✓
Near Wrigley		✓	✓	✓
Near Norman Wells		✓	✓	✓
Upstream from Arctic Red River		✓		✓

✓ = Selected site median closely approximates (within 15%) subbasin median value.

(✓) = Selected site median in vicinity of (within 25%) subbasin median value.

values to the overall characteristic values for the subbasin. The evaluation may be of use in the design of monitoring networks.

Within each subbasin there are similarities between values at a minimum of one of the selected sites and the aggregate median (for most of the physical parameters). The Bitumount site, Peace Point, Fort Simpson, Hay River, Great Bear Lake outlet, Slave River at Fitzgerald and Fort Providence have parameter median values that most closely approximate the respective subbasin medians.

Agreement between the compared values is dependent upon the spatial variability of physical parameter values within each subbasin. The low variation of colour, TDS and specific conductivity (Fig. 3.5) between sites in the Mackenzie subbasin results in good agreement with the overall subbasin value. Similarly, turbidity values in the Athabasca River are within the same range (Fig. 3.3) except for the most downstream site.

3.1.6 Conclusions

Physical characteristics of rivers in the Mackenzie drainage basin reflect the major physiographic subdivisions. Rivers in the Western Cordillera have relatively high turbidities owing to the sedimentary bedrock and high relief; those in the Interior Plain have relatively higher values of TDS, specific conductivity and colour. Shield rivers have low levels of each of the physical parameters.

Spatial patterns of the physical parameters in the Athabasca, Peace and Mackenzie rivers are due to variations in lithology, the discharge and suspended sediment regimes, and in-stream and tributary sources of dissolved and suspended components. The Great Slave and Great Bear lakes act as settling basins of suspended material and therefore provide waters of relatively lower turbidity to the Mackenzie River.

Rivers in the Western Cordillera and Interior Plain show seasonal fluxes of physical parameters in response to the discharge regime. Values of turbidity and colour are low over the winter, highly variable in spring and peak over the summer. Specific conductivity and TDS show concentration declines in the open water period owing to dilution by high flow. No seasonal variations are evident in the pH values. Insufficient data are available to permit a seasonal evaluation of physical parameters of the Shield area. Concentration changes of the physical parameters over time are not apparent.

Data for the physical parameters collected at the Bitumount, Peace Point, Fort Simpson, Hay River, Great Bear Lake outlet, Slave River at Fitzgerald, and Fort Providence selected sites are within 25% of values representing all sites in the respective subbasins. Data for these selected sites may, for some purposes, be adequate for characterizing the overall quality of the subbasin.

3.2 Major Ions

3.2.1 Introduction

Ions in natural waters originate from the weathering of minerals, atmospheric precipitation and anthropogenic sources. The major cations are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}); major anions are bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulphate (SO_4^{2-}) and carbonate (CO_3^{2-}).

Several of the ions (Ca^{2+}, SO_4^{2-}) are required by aquatic organisms, and their concentrations in water can therefore fluctuate with metabolic demands. Others (Mg^{2+}, K^{+}, Na^{+}, Cl^{-}) are also required for biological functions, but demands are frequently minor compared with available quantities. Concentrations of carbon dioxide, HCO_3^{-} and CO_3^{2-} buffer freshwater systems; the proportions of these at equilibrium control the ambient pH.

3.2.2 Major Ion Composition

The median concentration values for major ions (Table 3.3) were used to determine the proportion of ions present in each of the

Table 3.3 Median Values of Major Ion Concentrations for Mackenzie River Subbasins

Subbasin	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	CO_3^{2-}
Rivers								
Athabasca	34	11	8.4	1.0	130	2.0	21	0
Peace	33	9.0	3.8	0.8	117	1.2	19	0
Liard	35	7.4	1.7	1.3	111	0.7	26	0
Hay	50	9.5	14	-	135	3.8	69	0
Great Bear	17	6.5	3.7	-	65	4.6	14	0
Great Slave	31	6.5	6.6	1.0	103	6.1	19	0
Mackenzie	31	8.1	6.1	0.9	100	5.9	27	0
Lakes								
Athabasca	18	13	3.1	-	41	2.5	7.0	0
Peace	16	-	-	-	47	-	-	0
Great Bear	17	6.7	4.2	-	66	4.9	14	0
Great Slave	30	17	2.9	-	32	3.4	8.8	0

NOTE: All values are in milligrams per litre.

subbasins. Data from all locations within each subbasin (rivers and lakes treated separately) were aggregated for the calculations. Mean, median, minimum, maximum and main percentile values for selected sites are given in Table C-2 of Appendix C. Where K^{+} values were not available, the difference between anion and cation concentrations was used to estimate K^{+} and ion proportion diagrams.

3.2.2.1 Rivers

Major ion proportions for rivers of the subbasins are shown as rosette (ionic proportion) diagrams (Fig. 3.19). The diagrams show the dominance of Ca^{2+} and HCO_3^{-} in the rivers of each subbasin. The Athabasca and Peace subbasins have very similar ionic proportions. Both subbasins are largely underlain by sedimentary bedrock, with Paleozoic and Proterozoic formations at the headwaters, and Paleozoic representations in the vicinity of the mouth. The Liard River, in comparison, contains a greater proportion of SO_4^{2-} and less Na^{+}.

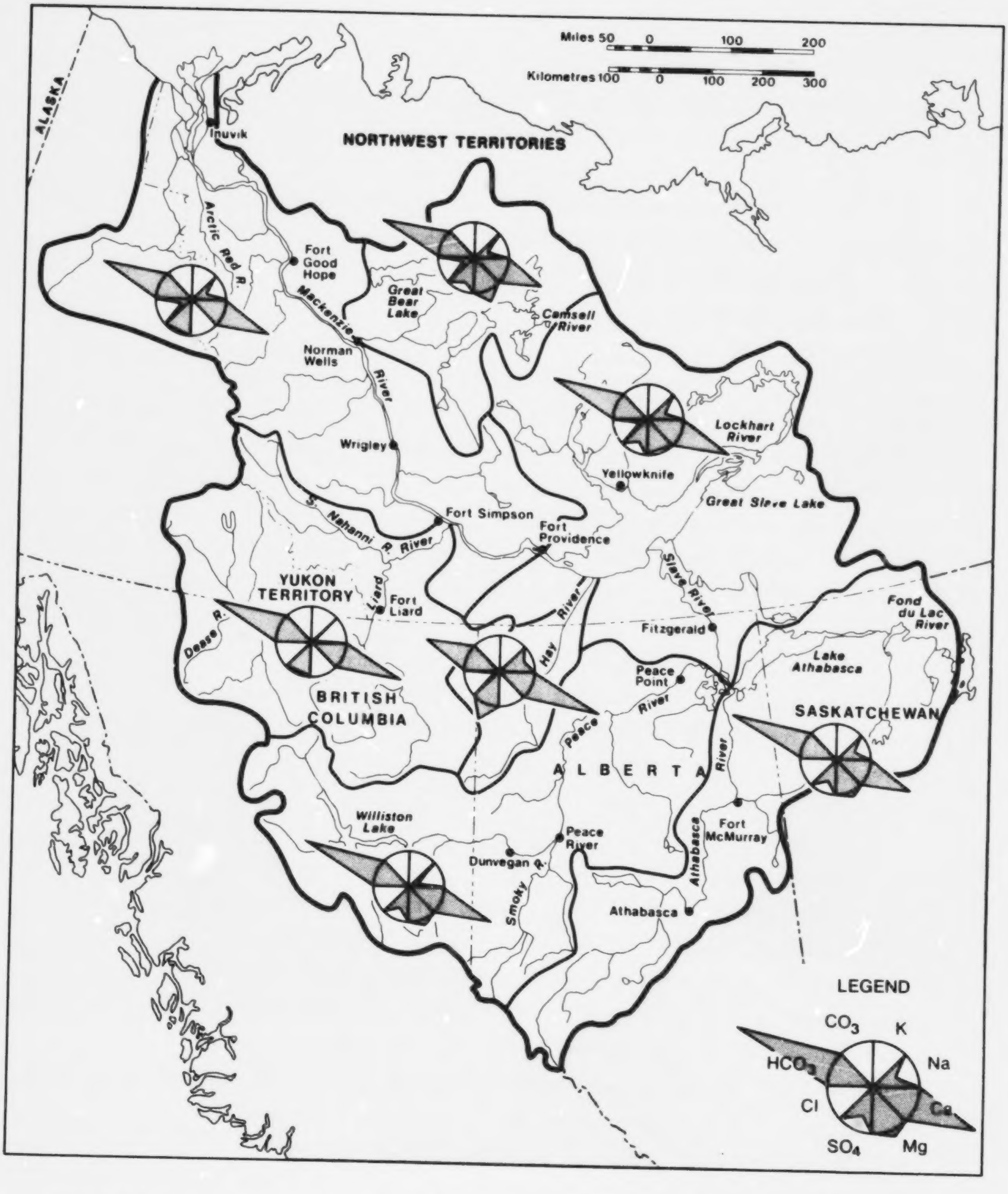


Figure 3.19 Ionic proportion diagrams for rivers of the Mackenzie River subbasins. Median values are expressed by the diagrams.

The watershed has a greater area of Paleozoic and Proterozoic bedrock, which are sources of Ca^{2+}, HCO_3^-, Mg^{2+} and SO_4^{2-}. The lower proportion of Na^+ likely reflects a lesser occurrence of illites and evaporites in the Liard than in the Athabasca or Peace watersheds.

The Hay River contains the lowest proportion of HCO_3^- and the highest of SO_4^{2+} and Na^+ of all the subbasins in the Mackenzie drainage. Elevated Na^+ proportions reflect the abundance of illite in marine clays and shales.

The Great Slave and Great Bear subbasins have notable proportions of Na^+ and Cl^-. Calcium and HCO_3^- proportions are relatively low in the Great Bear region probably because 75% (12/16) of the river monitoring sites are located in the carbonate-poor Precambrian Shield. The presence of Shield bedrock in the Great Slave subbasin is not reflected by the ion proportions, as an equal number of stations are located in the Shield and Interior Plain regions.

River waters in the Mackenzie River subbasin show Na^+ and Cl^- proportions similar to those found in the Great Slave and Great Bear subbasins, and Ca^{2+} and HCO_3^- proportions similar to those in the Athabasca, Peace and Liard systems.

3.2.2.2 Lakes

Ion proportions in lakes of the Great Bear, Great Slave and Athabasca subbasins (Fig. 3.20) differ markedly from those in the rivers. Lakes have lower proportions of HCO_3^- and Ca^{2+} and contain significantly more Mg^{2+} than rivers. All lake sites in the Great Bear subbasin are located in the eastern (Shield) portion of the subbasin; of all three subbasins with lake ion data, this subbasin contains the lowest proportion of Mg^{2+}. The Great Slave system contains approximately equal proportions of Mg^{2+} and Ca^{2+}. Lakes in the Athabasca subbasin have greater proportions of Mg^{2+} than of Ca^{2+}. This suggests an increase in the Mg^{2+} to Ca^{2+} ratio with a decrease in basin area underlain by Precambrian Shield. In the Great

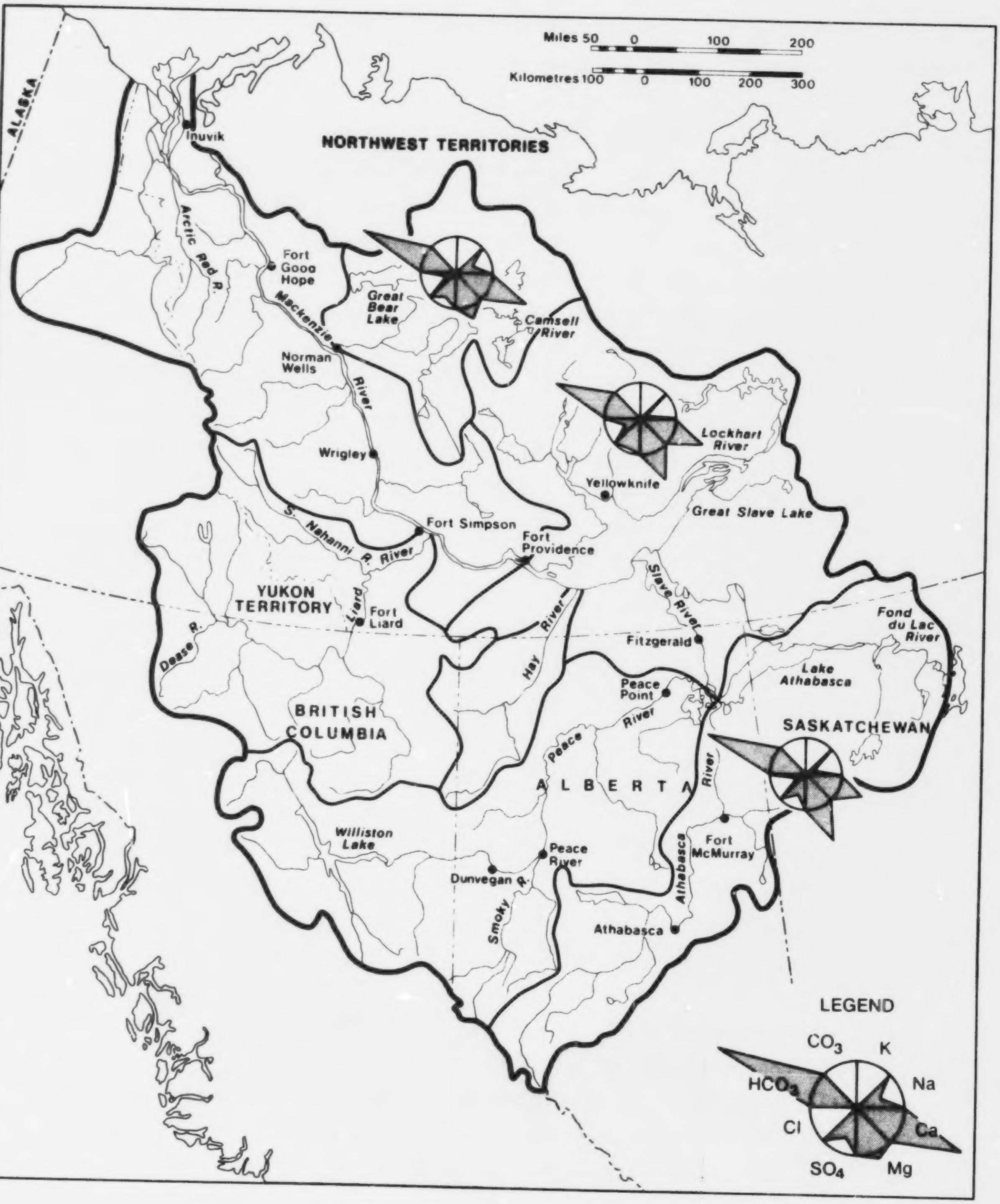


Figure 3.20 Ionic proportion diagrams for lakes of the Mackenzie River subbasins. Median values are expressed by the diagrams.

Slave subbasin, 9 of the 12 lake stations are located in the Shield, whereas in the Athabasca subbasin only two of five stations are located in the Shield.

It is unusual in freshwater for Mg^{2+} to be present in greater proportion than Ca^{2+}, because Mg^{2+} is less abundant than Ca^{2+} in all rock types. The greater than expected proportions of Mg^{2+} may be due to the dissolution of dolomite (Ca, Mg, CO_3^{2-}) (a possibility in the Great Slave subbasin), reaction with Mg-silicate minerals and/or the weathering of olivine ((Mg, Fe) SiO_4).

The larger proportion of Mg^{2+} in lake than in river water and of Ca^{2+} in river than in lake water reflects the chemistry of these cations. Since magnesium ions are more strongly attracted to water molecules than are Ca^{2+} ions, Mg^{2+} tends to remain in solution over an extended period of time, whereas dependent upon ambient pH conditions, Ca^{2+} readily precipitates (U.S. Geological Survey, 1970). Because of the continuous change occurring in flowing systems, departure from equilibrium occurs. A close approach to equilibrium conditions is expected in more stable lake systems.

3.2.3 Spatial Variations

Spatial changes in ion proportions within the subbasins occur in part owing to variations in bedrock composition. The Athabasca subbasin (Fig. 3.21) shows downstream declines in the proportion of Ca^{2+}, HCO_3^- and Mg^{2+} accompanied by increases in the proportions of Na^+, Cl^- and SO_4^{2-}. The Ca^{2+} and HCO_3^- at the headwaters originate from sedimentary carbonates. Downstream declines in Ca^{2+} and HCO_3^- and concurrent increases in Na^+ and Cl^- reflect the transition from Paleozoic to Cretaceous strata. Elevated salt (Na^+ and Cl^-) levels at Bitumount may be due not only to marine deposits but also to saline springs that feed Clearwater River and possibly anthropogenic sources. The Fond du Lac site has low proportions of Ca^{2+} and HCO_3^- due to the paucity of carbonate rocks in the Precambrian Shield.

A similar situation occurs in the Peace River subbasin (Fig. 3.22). Carbonate rocks in the headwaters are responsible for the dominance of Ca^{2+} and HCO_3^- at the Highway 29 and Dunvegan sites. The Smoky River, located largely on marine Cretaceous strata, contains elevated proportions of Na^+ and Cl^- compared with those in the mainstem river water. Downstream increases in SO_4^{2-} and Na^+ may be from anthropogenic sources and the Smoky River, respectively.

Downstream changes in ion proportions in the Mackenzie River subbasin (Fig. 3.23) are not readily apparent. Trends in average ion concentrations (Fig. 3.24) indicate gradual downstream increases of all ions except potassium. Concentrations of Na^+ and Cl^- peak, while those of Ca^{2+}, HCO_3^- and SO_4^{2-} decline at Norman Wells. The

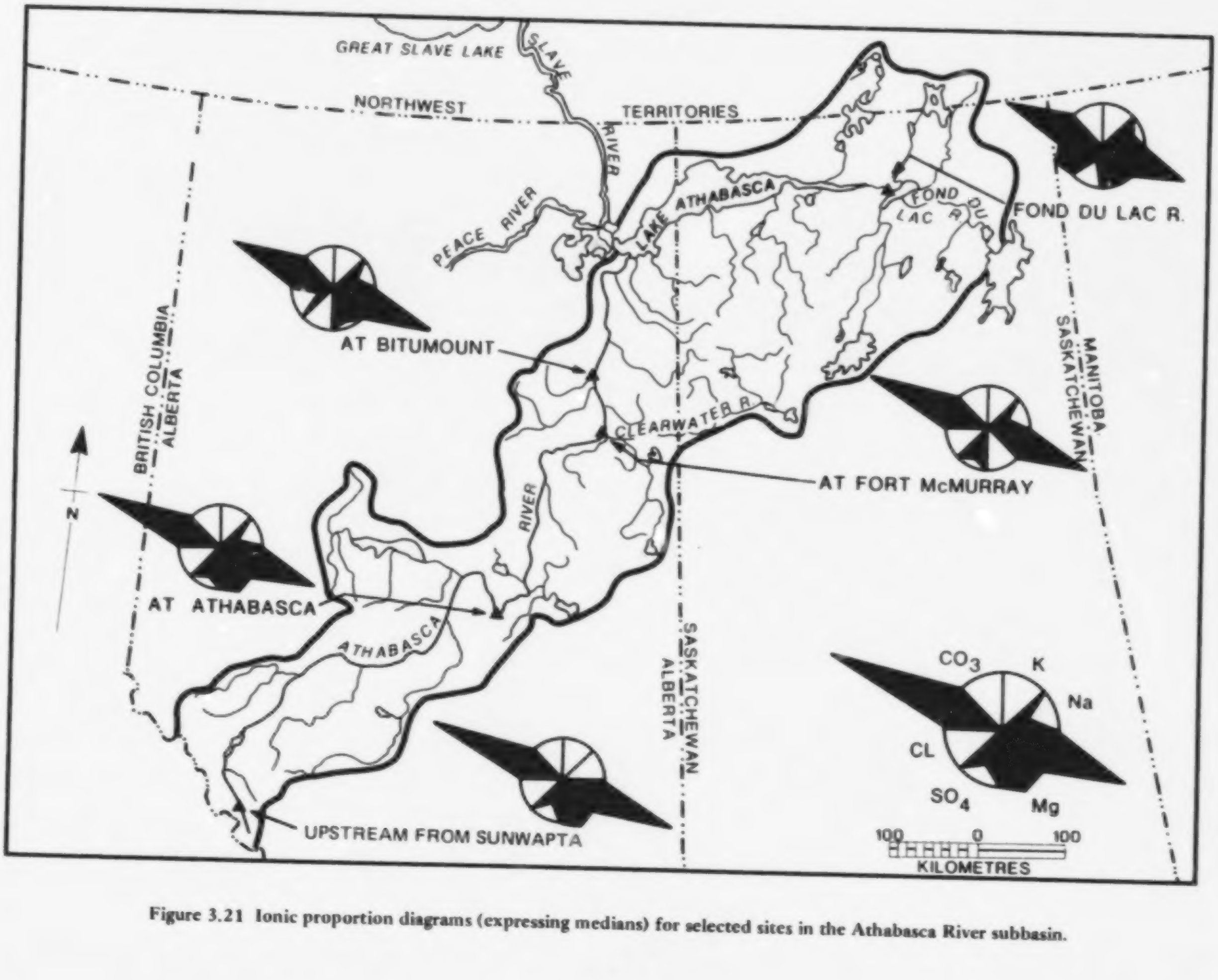


Figure 3.21 Ionic proportion diagrams (expressing medians) for selected sites in the Athabasca River subbasin.

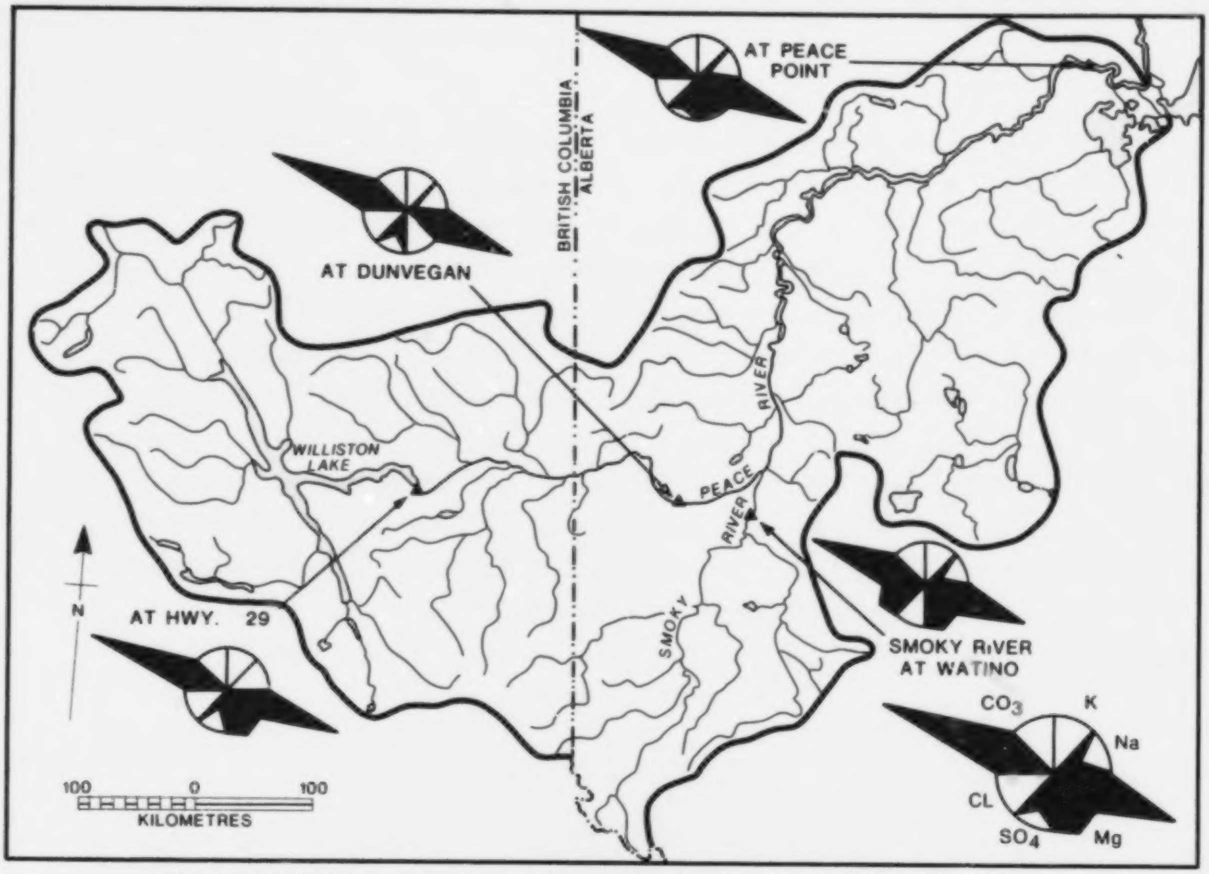


Figure 3.22 Ionic proportion diagrams (expressing medians) for selected sites in the Peace River subbasin.

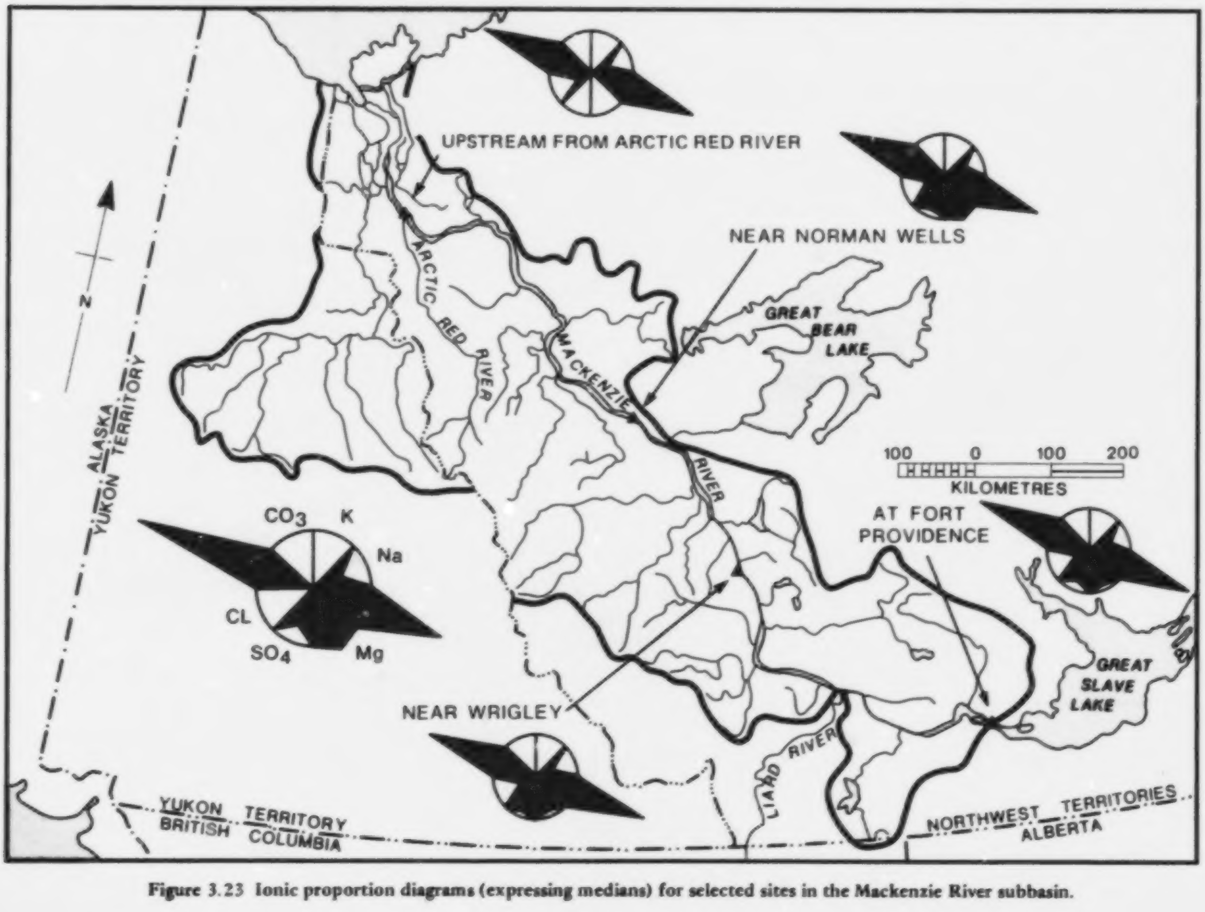


Figure 3.23 Ionic proportion diagrams (expressing medians) for selected sites in the Mackenzie River subbasin.

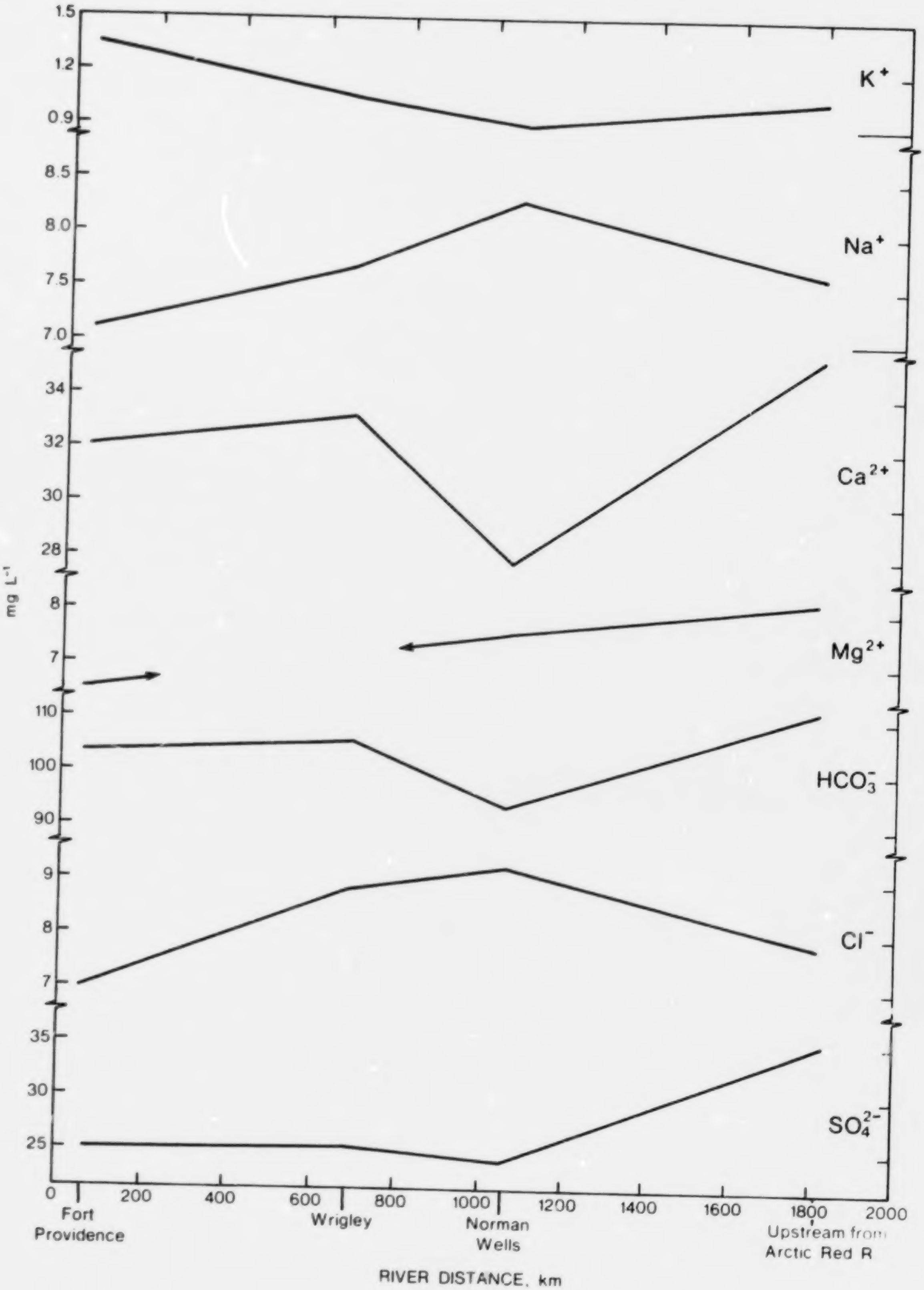


Figure 3.24 Downstream trends in major ion average concentrations in the Mackenzie River subbasin.

Na^+ and Cl^- peaks reflect the evaporitic bedrock underlying the Norman Wells area. The increase in Ca^{2+} and SO_4^{2-} upstream from the Arctic Red River may be due to gypsum deposits in the area.

3.2.4 Seasonal Variations and Interparameter Relationships

Variations in ion concentrations occur over the hydrologic year in the Mackenzie River basin, reflecting discharge flux, variations in rates at which minerals are weathered or leached from rocks or soils, in-stream chemical reactions and biological utilization patterns. Ion seasonality was evaluated at selected sites using the monthly mean concentration of all available data. The mean was chosen over the median, as it was desirable to include in the seasonal evaluation the entire range of concentrations recorded each month.

Variations in ion concentrations at Athabasca show distinct cyclical changes over the year corresponding to the discharge regime. The Cl^-, Ca^{2+}, and HCO_3^- (Fig. 3.25) and Mg^{2+} and SO_4^{2-} (Figure D-1, Appendix D) reach their highest annual concentration over the December-March period, the time of lowest discharge (Fig. 3.15). During this period, groundwater flow is expected to be the major ion supplier to the feeder systems. Discharge increases dramatically in April and ion concentrations consequently decline. Concentrations continue to decline as background levels of the ions are diluted and accumulated salts are flushed by increases in discharge. Although the discharge peaks in July, ion concentrations reach annual low levels in August due to the response lag time in the drainage basin. Declining discharges in the fall are accompanied by increasing levels of ions which return to baseflow concentrations in December. The potassium ion (Fig. 3.25) behaves differently; peak concentrations occur in April, possibly due to initial mobilization of K^+ by increasing discharge, followed by the inverse ion concentration - discharge relationship observed for the other ions. Similar seasonal variations occur in the Hay and Smoky rivers (e.g. Ca^{2+}, HCO_3^-; Figure D-2, Appendix D).

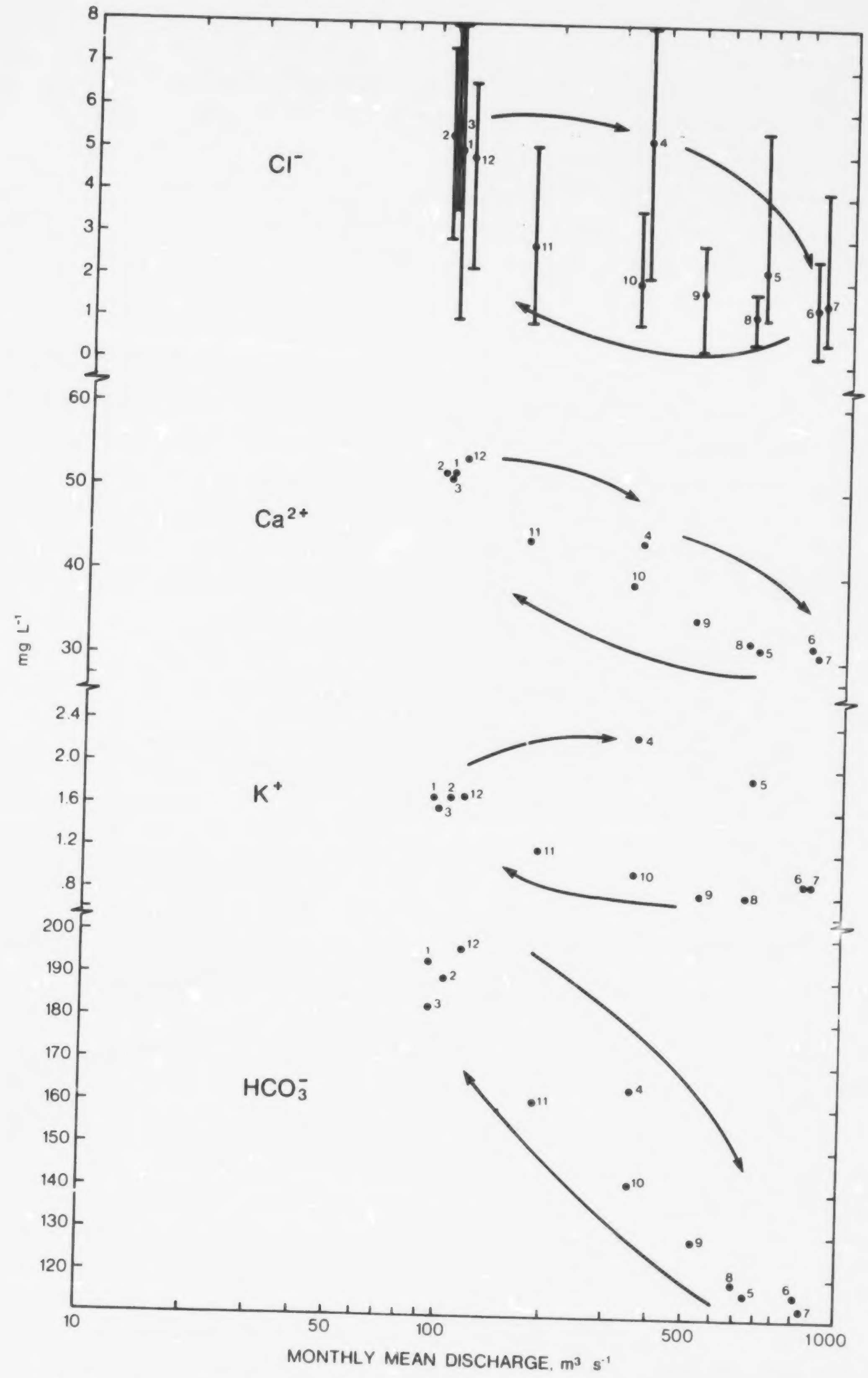


Figure 3.25 Seasonal variation of Cl⁻, Ca²⁺, K⁺ and HCO_3^- at Athabasca River at Athabasca (00AL07BE0001). Numbers refer to month of the year. Bars indicate the range of data per month over the period of record.

Changes in ion concentrations in the Liard River (Fig. 3.26) differ slightly from those in the Athabasca, Smoky and Hay rivers, as increasing concentrations in the fall are higher than the decreasing levels in spring and early summer (April-June). This appears to be related to the seasonally varying contributions of the different chemical characteristics related to overland flow, interflow and baseflow components to the total flow.

Seasonality of major ions in rivers located in the Precambrian Shield (e.g., Cl^-, Figure 3.27; Ca^{2+}, Figure D-3, Appendix D) differs from that in the Western Cordillera and Interior Plain, reflecting the lesser variation in discharge over the hydrologic year and differing rates of mineral dissolution from Shield materials. Ion concentrations in the Camsell River (Fig. 3.28) are relatively high over the winter months, decline in early summer (June) and rise in the fall. The later

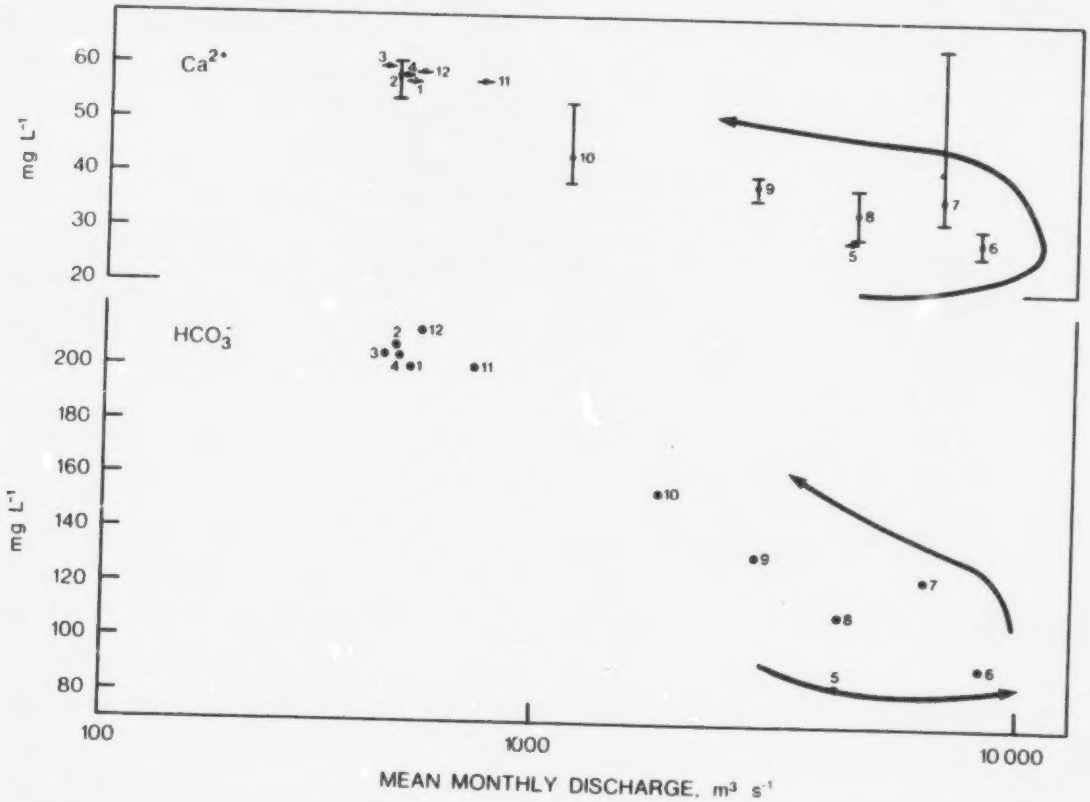


Figure 3.26 Seasonal variation of Ca^{2+} and HCO_3^- at Liard River at Fort Simpson (00NW10ED0002). Numbers refer to month of the year. Bars indicate the range of data per month over the period of record.

decline in the Camsell compared with rivers in the Western Cordillera coincides with the later spring breakup in the Shield region (Appendix A). The Fond du Lac and Lockhart rivers also demonstrate an inverse relationship between ion concentration and discharge; in the former, the relationship holds for all ions, whereas in the latter the relationship is illustrated for Ca^{2+} but is refuted by Cl^- and HCO_3^-. Relatively high concentrations of Cl^- and HCO_3^- in November-December coincide with annual high discharges, suggesting mobilization of these anions from contributing areas by high flows and with significant groundwater flows that are rich in mineral content.

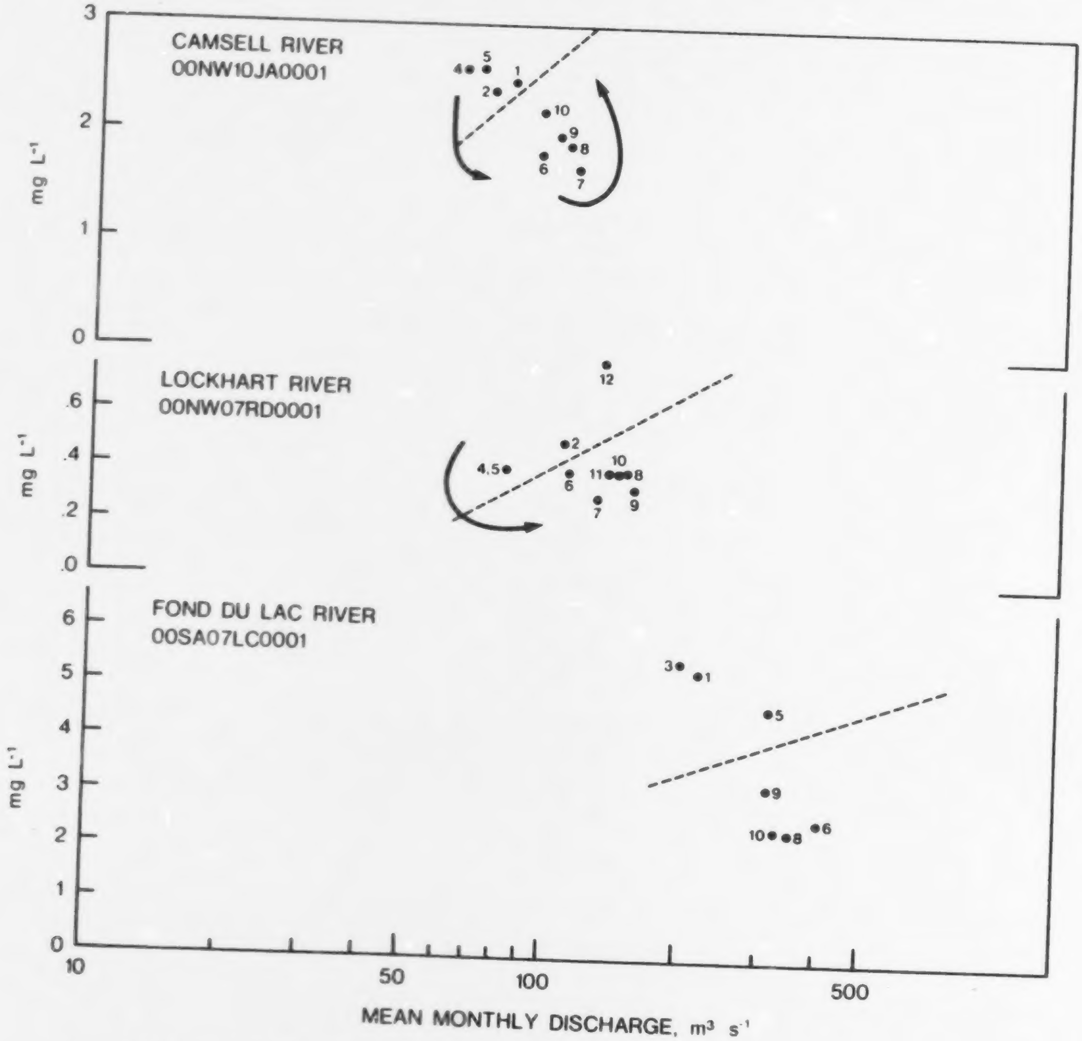


Figure 3.27 Seasonal variation of Cl^- in rivers in the Precambrian Shield. Numbers refer to month of the year.

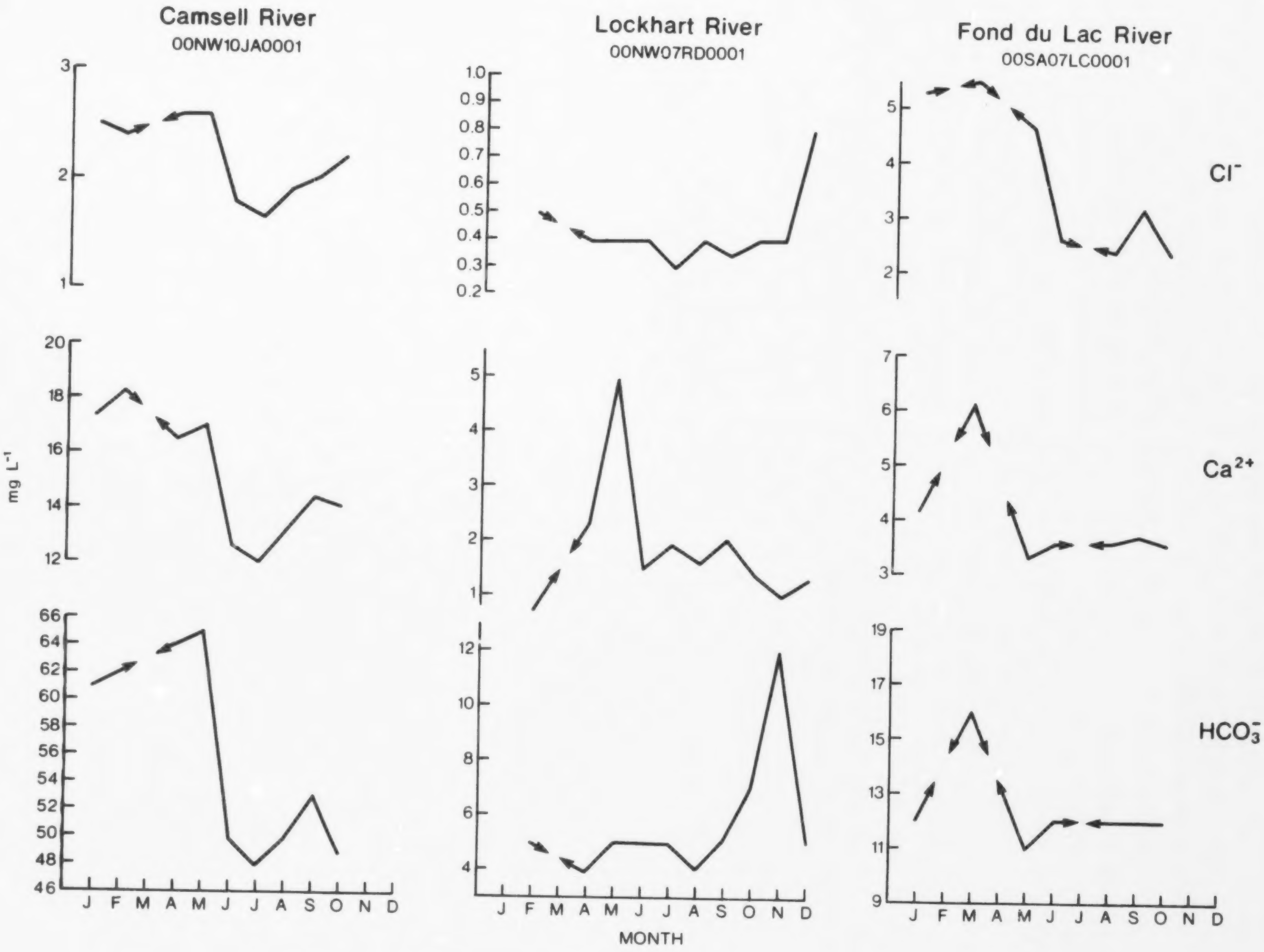


Figure 3.28 Annual variation of Cl^-, Ca^{2+} and HCO_3^- in rivers in the Precambrian Shield.

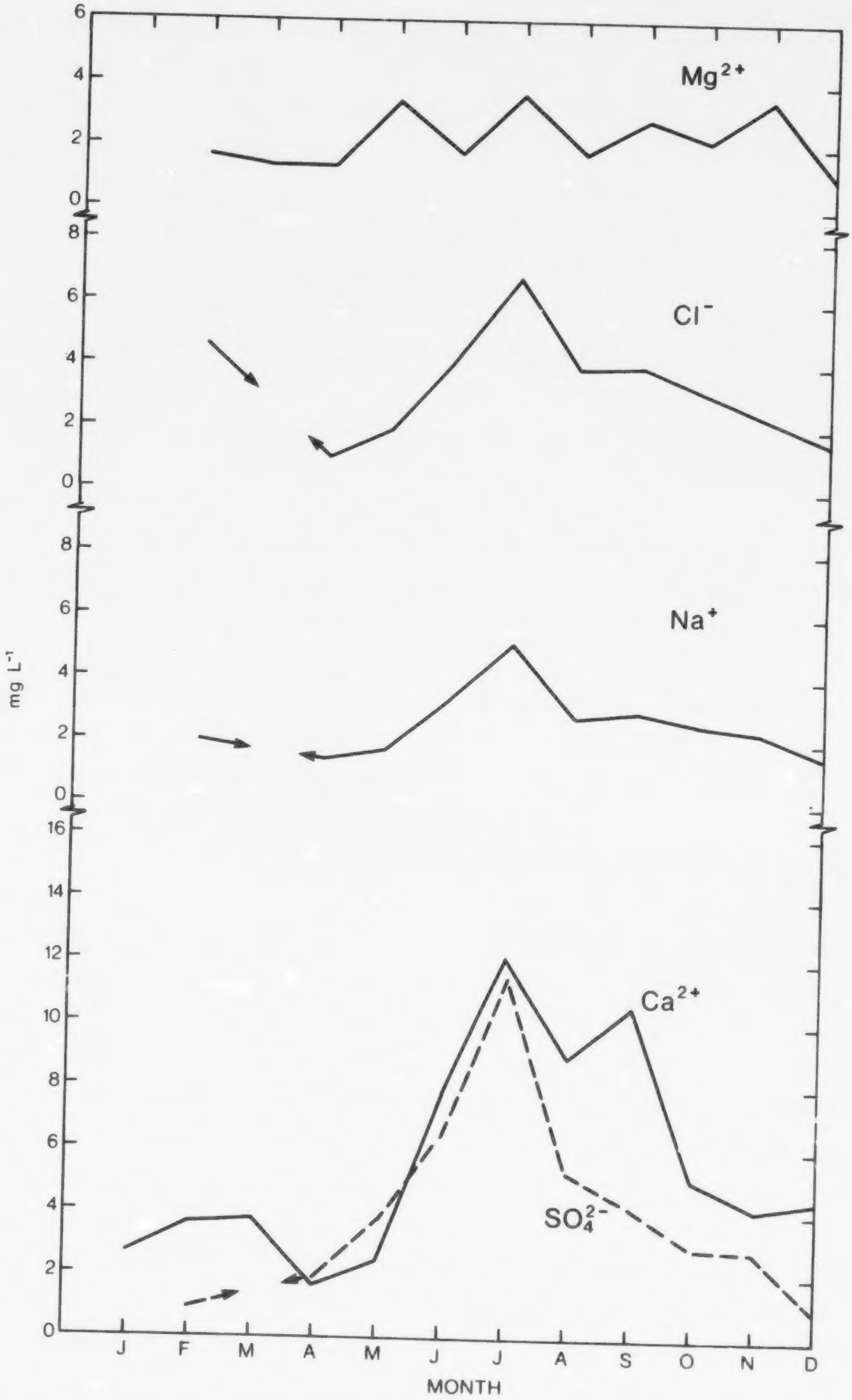


Figure 3.29 Annual variation of major ions in Great Slave Lake at Yellowknife Bay (01NW07SB0003).

The seasonal trends of ion concentrations in lakes differ significantly from those in rivers. Baseflow ion contributions to Great Slave Lake are augmented over the summer period (Fig. 3.29) by direct inputs of overland flow as well as by river inputs of relatively higher ion concentrations (Figs. 3.25 to 3.27) immediately prior to this time period.

Ion concentrations in the Mackenzie River show slight downstream changes in seasonality, reflecting the seasonal changes noted in rivers

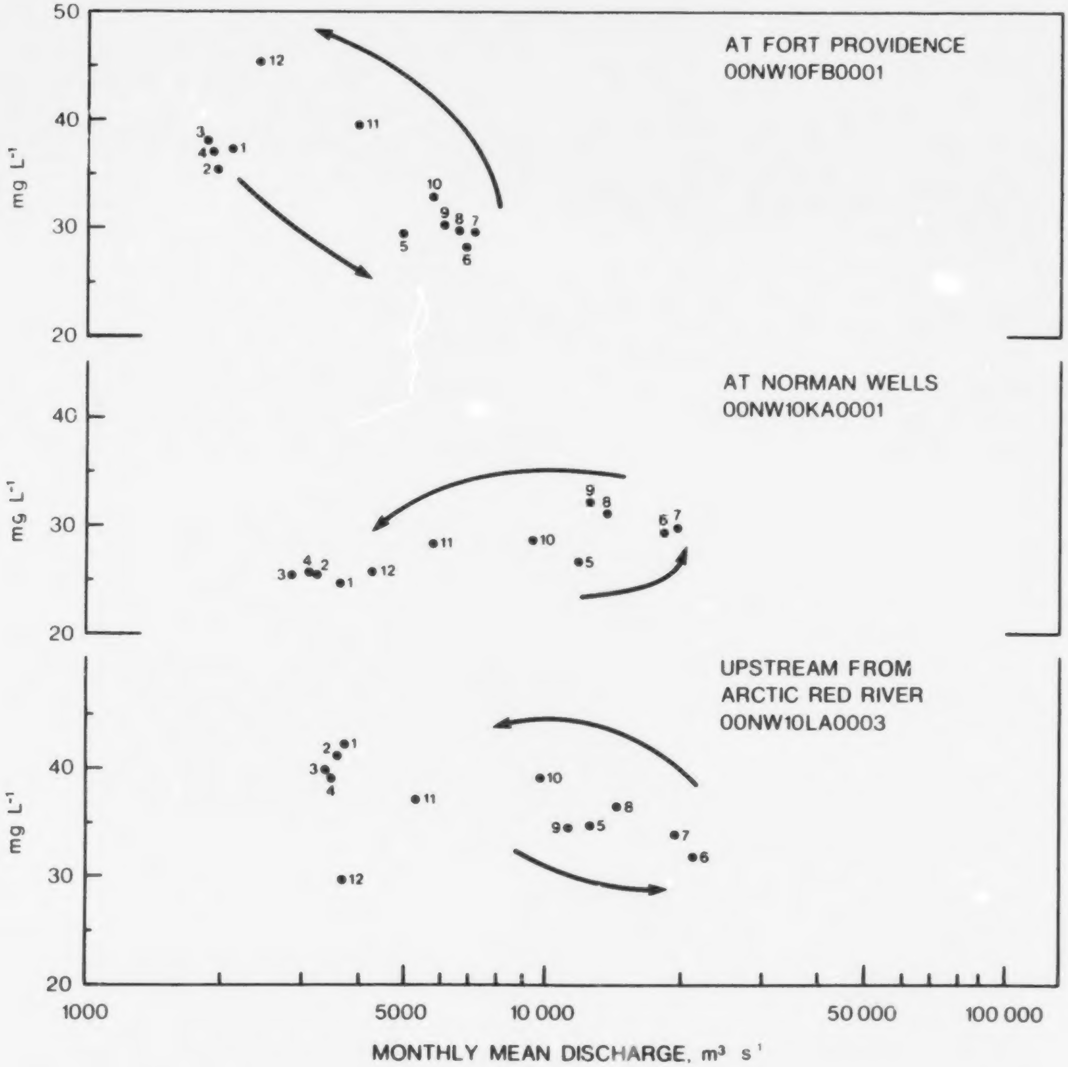


Figure 3.30 Seasonal variation of Ca^{2+} at selected sites on the Mackenzie River. Numbers refer to month of the year.

throughout the basin and lake ion inputs. Seasonality of Ca^{2+} (Fig. 3.30) and Cl^- (Figure D-4, Appendix D), respectively, are affected at Fort Providence by discharge flux, and ion supply from Great Slave Lake over the summer period. River concentrations of Ca^{2+} at Norman Wells over the winter months are dominated by discharge and Ca^{2+} concentrations at Fort Providence. The Ca^{2+} concentration at Norman Wells over the summer months reflects the approximately equivalent flow and Ca^{2+} concentration contributions from Fort Providence and the Liard River.

Seasonal ion trends upstream from the Arctic Red River on the Mackenzie River are similar to the discharge-related ion concentration trends noted previously. Calcium ion concentrations at Fort Providence, Norman Wells and Arctic Red, and Cl^- concentrations at Norman Wells, are higher when these ion levels rise in the fall than when concentrations decline in the spring. This may be attributed to ion supply from the Great Slave and Great Bear lakes to the mainstem river, significantly augmenting the depleted in-stream ion concentrations over the fall period.

The strong positive association of Ca^{2+} and HCO_3^- with specific conductivity is illustrated in Figures 3.31a and b. Data include all seasons and years of record. The close relationship between the parameters is expected to hold for all ions and in all subbasins.

3.2.5 Comparison of Subbasin and Selected Site Medians

The similarity of major ion concentrations at the selected sites to the overall subbasin concentrations was evaluated by comparison of the site (Table C-2, Appendix C) and subbasin (Table 3.3) medians. Table 3.4 subjectively expresses the proximity of the site ion medians to the subbasin ion medians. Bitumount, Peace Point, South Nahanni River, Hay River, Great Bear Lake outlet, Slave River at Fitzgerald and Mackenzie River upstream from the Arctic Red River are the selected sites that have median ion values that most closely approximate (within 15% or 25%) the respective subbasin medians.

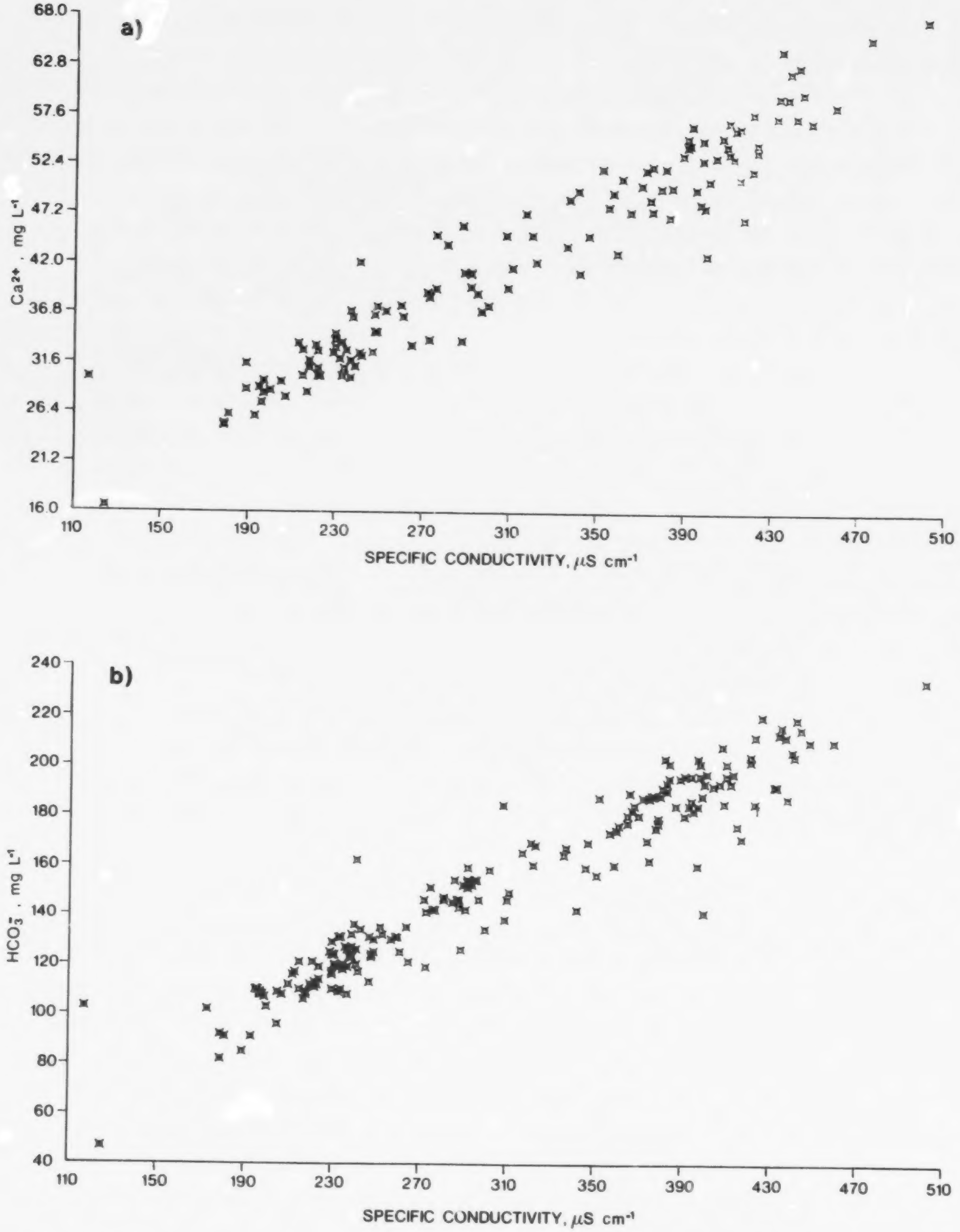


Figure 3.31 Relationship between Ca^{2+} and HCO_3^- and specific conductivity at Athabasca River at Athabasca (00AL07BE0001).

Table 3.4 Comparison of Subbasin and Selected Site Medians - Major Ions

Subbasin, selected site	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	CO_3^{2-}
Athabasca								
Upstream from Sunwapta								✓
At Athabasca	✓	✓	✓	✓	(✓)	✓	✓	✓
At Fort McMurray	✓	✓	✓	✓			✓	✓
At Bitumount	✓	✓	✓	✓	✓	✓	✓	✓
Fond du Lac River						✓		✓
Peace								
At Hwy 29	✓	(✓)		✓				✓
At Dunvegan	✓	(✓)	✓	✓	✓		✓	✓
At Peace Point	✓	(✓)	✓	✓	✓	✓	✓	✓
Smoky River at Watino		✓		✓				✓
Liard								
Upstream from Dease River	✓		✓	(✓)				✓
At Fort Liard	✓	(✓)	✓	✓		(✓)	✓	✓
Upstream from Fort Simpson	✓	✓	✓	(✓)		(✓)	✓	✓
South Nahanni River	✓	(✓)	✓	(✓)	✓	✓	✓	✓
Hay								
Hay River at mouth	✓	✓	✓			✓	✓	✓
Great Bear								
Great Bear Lake at outlet	✓	✓	✓		✓	✓	✓	✓
Camsell River	(✓)	✓	(✓)					
Great Slave								
Slave River at Fitzgerald	✓	✓	✓	✓	✓	✓	✓	✓
Lockhart River								
Yellowknife Bay				✓				
Mackenzie								
At Fort Providence	✓				✓			✓
Near Wrigley	✓		✓	✓	✓		✓	✓
Near Norman Wells	✓	✓		✓				✓
Upstream from Arctic Red River	✓	✓	✓	✓		✓	✓	✓

✓ = Selected site median closely approximates (within 15%) subbasin median.

(✓) = Selected site median in vicinity of (within 25%) subbasin median value.

3.2.6 Conclusions

Ion concentrations and proportions in rivers and lakes of the Mackenzie River basin reflect the diversity of the bedrock geology. Waters in all subbasins are dominated by Ca^{2+} and HCO_3^-. Lakes of the subbasins are dominated by Ca^{2+} and higher proportions of Mg^{2+} than rivers due to the chemistry of these cations. Spatial variations in each of the subbasins are directly related to the variable bedrock composition.

Seasonal ion concentrations in the Cordillera and Interior Plain regions are at annual high levels over the winter when discharge is at lowest volume, decline in spring as discharge increases, reach a summer low, then increase in fall as flows decline. Seasonality in the Shield region is less variable due to the more stable flow regime. Ion concentrations in lakes peak over the summer period due to fluvial inputs. Mackenzie River ion concentrations show seasonal variations in response to the relative contributions from the tributaries and lakes.

The following selected sites characterize, within 25%, ion concentrations for the respective subbasins: Bitumount, Peace Point, South Nahanni River, Hay River, Great Bear Lake outlet, Slave River at Fitzgerald and Mackenzie River upstream from the Arctic Red River.

3.3 Nutrients

3.3.1 Introduction

This group of parameters comprises the elements of nitrogen, phosphorus and carbon in their various chemical forms. Conversion from one form to another takes place under varying physical, chemical and biological conditions. Several of the nitrogen and phosphorus forms are essential for the growth of plants and, when present in sufficient quantities, may contribute to eutrophication. The abundance and relative proportions of the various species in water indicate the health of the water body in terms of biological activity, oxygen content, and natural and anthropogenic sources of the nutrients. The amount and species of carbon in water reflect the composition of organic matter present, biochemical and chemical oxygen demands and vegetation growth cycles.

3.3.2 Mean Values for the Subbasins

The mean and range of nutrient concentrations for each subbasin are presented in Table 3.5. Percentiles for the nutrient parameters at selected sites are given in Table E-1 of Appendix E.

Differences in nitrogen, phosphorus and carbon concentrations between the subbasins reflect regional variations in vegetation, geology, biological activity and land use, and physical characteristics of the drainage waters. Due to large spatial and temporal fluctuations in nutrient concentrations reflecting supply and biological demand, the mean as well as the range of values for each subbasin and the standard deviation of the means are examined to evaluate interbasin variations.

3.3.2.1 Rivers

Figure 3.32 shows interbasin levels of nutrients in rivers. The Great Bear Lake subbasin has the lowest means and narrowest range of values for the nitrogen, phosphorus and carbon species investigated. The relatively low values reflect a lesser natural nutrient supply from the Shield area, less biological growth and the low variability of flow of rivers entering and draining Great Bear Lake.

The Hay River subbasin has high mean values of total organic carbon (TOC), dissolved organic carbon (DOC), and total dissolved phosphorus (TDP). The high productivity associated with the bogs in the Interior Plain explains the high organic values. Elevated TDP levels reflect the greater amount of phosphorus in circulation from decay of vegetation. Regeneration from bottom sediments by wind-induced circulation in the shallow ponds may be an additional factor in explaining the high TDP mean. The relatively high DOC values in the Liard and Great Slave subbasins and the high TDP mean in the Great Slave may reflect the influence of productive waters in the Interior Plain

Table 3.5 Mean and Range of Nutrient Concentrations in Mackenzie River Subbasins

Subbasin	Nitrogen				Phosphorus		Carbon	
	Dissolved nitrogen	Dissolved NO_2-NO_3	Ammonia/ ammonium	Total Kjeldahl nitrogen	Total dissolved phosphorus	Total phosphorus	Dissolved organic	Total organic
Rivers								
Athabasca	0.30 (0.03-2.30)	0.15 (0.005-7.20)	0.10 (0)	0.42 (0.10-16.10)	0.009 (0.003-0.064)	0.050 (0.005-1.00)	5.6 (0.5-14.0)	22.3 (0.5-295)
Peace	0.22 (0.08-1.10)	0.09 (0.005-5.30)	0.10 (0)	0.98 (0.10-16.10)	0.012 (0.003-0.064)	0.072 (0.005-1.00)	6.0 (2.0-14.0)	12.5 (0.5-99)
Liard	0.12 (0.01-0.26)	0.14 (0.005-3.0)	-	0.71 (0.50-2.80)	0.004 (0.003-0.013)	0.072 (0.003-1.10)	30.5 (1.0-41)	7.3 (0.5-46)
Hay	0.82 (0.38-1.25)	0.21 (0.005-0.588)	-	1.03 (0.80-1.20)	0.049 (0.003-0.062)	0.058 (0.013-0.140)	24.0 (18.0-26)	33.2 (15.0-80)
Great Bear	0.17 (0.10-0.24)	0.09 (0.005-0.470)	-	0.36 (0.10-0.60)	<0.003 (0)	0.008 (0.003-0.051)	3.4 (1.0-9.0)	6.6 (1.0-89)
Great Slave	0.24 (0.16-0.39)	0.19 (0.005-7.20)	-	0.64 (0.005-2.90)	0.025 (0.002-0.063)	0.054 (0.005-0.337)	12.5 (5.0-26)	15.1 (4.0-53)
Mackenzie	0.15 (0.025-0.42)	0.14 (0.005-5.40)	-	0.72 (0.100-5.70)	0.004 (0.003-0.016)	0.077 (0.003-3.0)	4.9 (1.0-13.0)	10.8 (0.5-175)
Lakes								
Athabasca	-	0.28 (0.005-13.4)	-	0.70 (0)	0.008 (0.003-0.02)	0.022 (0.003-0.330)	-	12.5 (1.5-413)
Peace	-	0.06 (0.02-0.31)	-	-	-	-	-	12.7 (3.0-45)
Great Bear	-	9.24 (0.009-48.6)	-	-	0.005 (0.003-0.008)	0.028 (0.003-0.330)	-	3.5 (2.0-9.0)
Great Slave	-	0.75 (0.005-13.4)	-	-	0.009 (0.003-0.02)	0.021 (0.004-0.05)	-	6.7 (2.0-16.0)

NOTE: Values are given in milligrams per litre; range is given in parentheses.

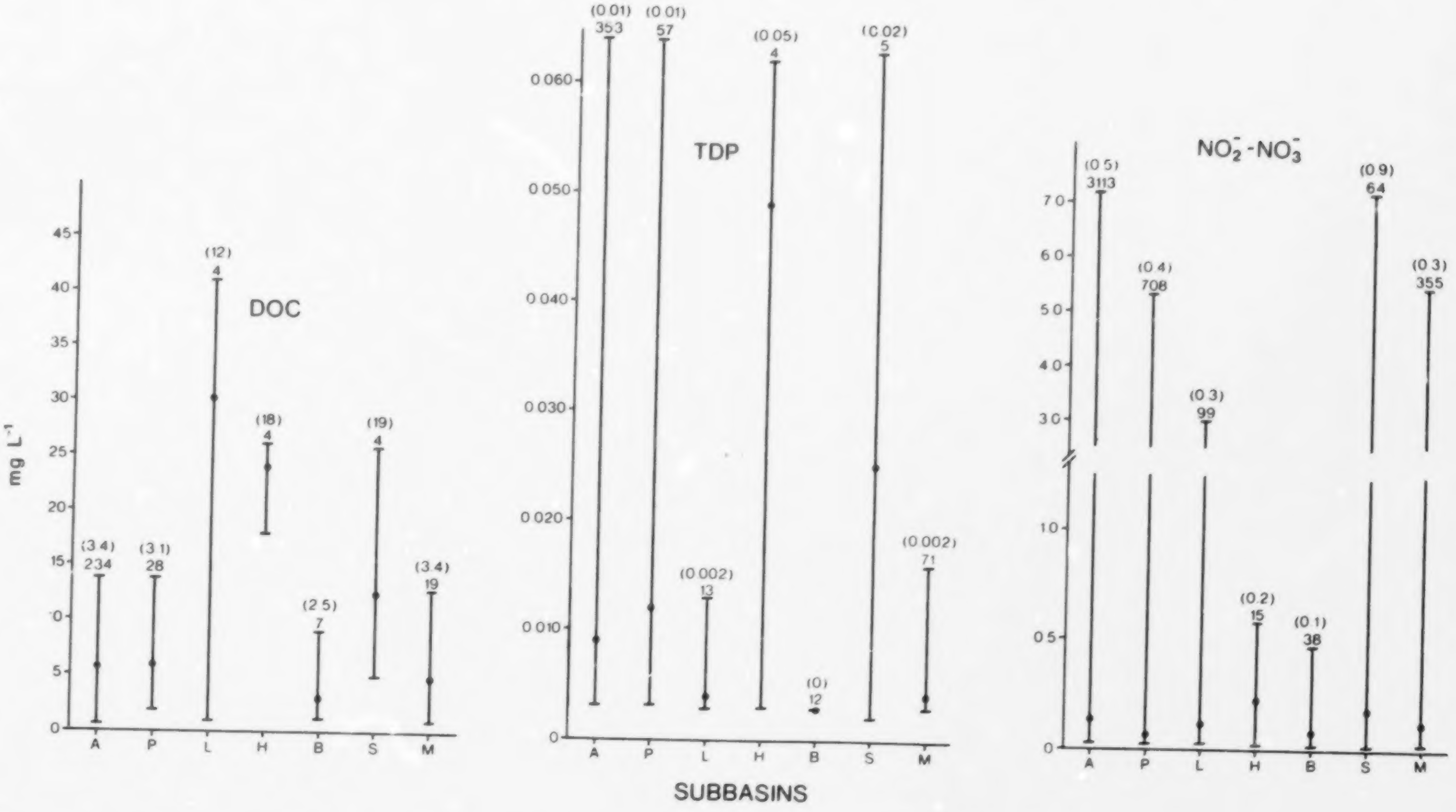


Figure 3.32 Interbasin variations in the mean nutrient concentration of rivers. A – Athabasca; P – Peace; L – Liard; H – Hay; B – Great Bear; S – Great Slave; M – Mackenzie. Numbers indicate sample size; numbers in parentheses give standard deviation.

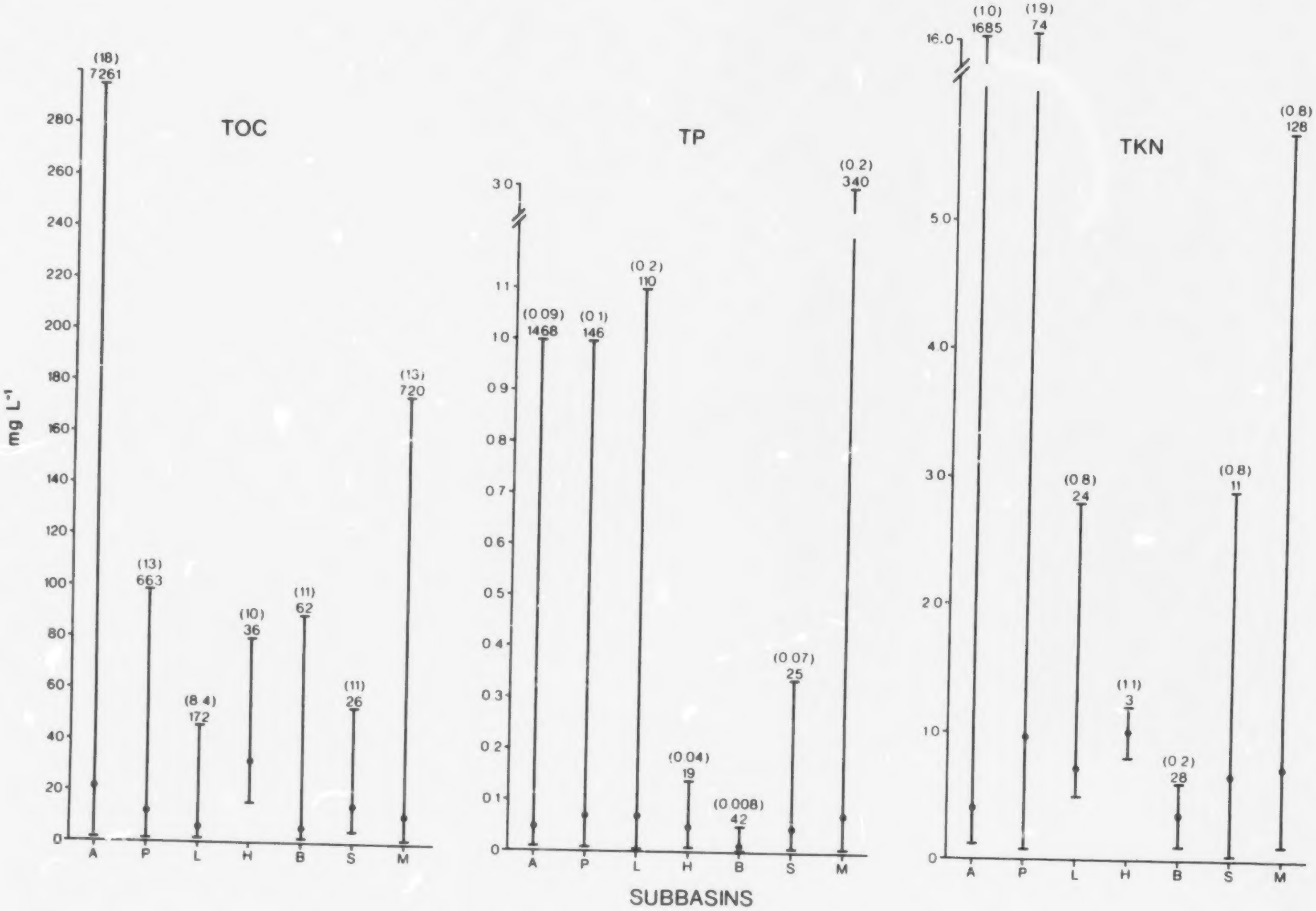


Figure 3.32 Continued.

portions of the subbasins on the overall composition of the subbasin waters.

Levels of total phosphorus (TP) appear similar for all subbasins. The Athabasca, Peace, Liard and Mackenzie River subbasins show greater variability than the Hay, Great Bear Lake and Great Slave Lake subbasins. This may be due, in part, to lesser variation in discharges in rivers draining lakes and low sediment transport of the Shield in the latter two subbasins, and the dampening of flows in the Hay subbasin by water storage in bogs.

Interbasin variation in mean nitrite-nitrate (NO_2^- - NO_3^-) values is minor. The range of values for total Kjeldahl nitrogen (TKN) and NO_2^- - NO_3^- is considerably narrower in the Hay and Great Bear than in the remaining subbasins, probably due to the less variable discharge regime in the former subbasins.

Interbasin variations in nutrient content reflect natural differences between the Western Cordillera, Interior Plain and Shield regions. Variability in the nutrient values appears to be directly related to the discharge regime.

3.3.2.2 Lakes

Interbasin variations in nutrient values in lakes are shown in Figure 3.33. Data were not available for those nutrient species that are not presented.

The mean value of NO_2^- - NO_3^- is an order of magnitude higher in the Great Bear Lake than in the Athabasca, Peace and Great Slave Lake subbasins; the reason for this is not known. In the Athabasca, Great Bear and Great Slave subbasins, the means and ranges are greater in the lakes than rivers. The values suggest a greater temporal and seasonal variation and greater amounts of NO_2^- - NO_3^- for bioutilization in the lakes than rivers.

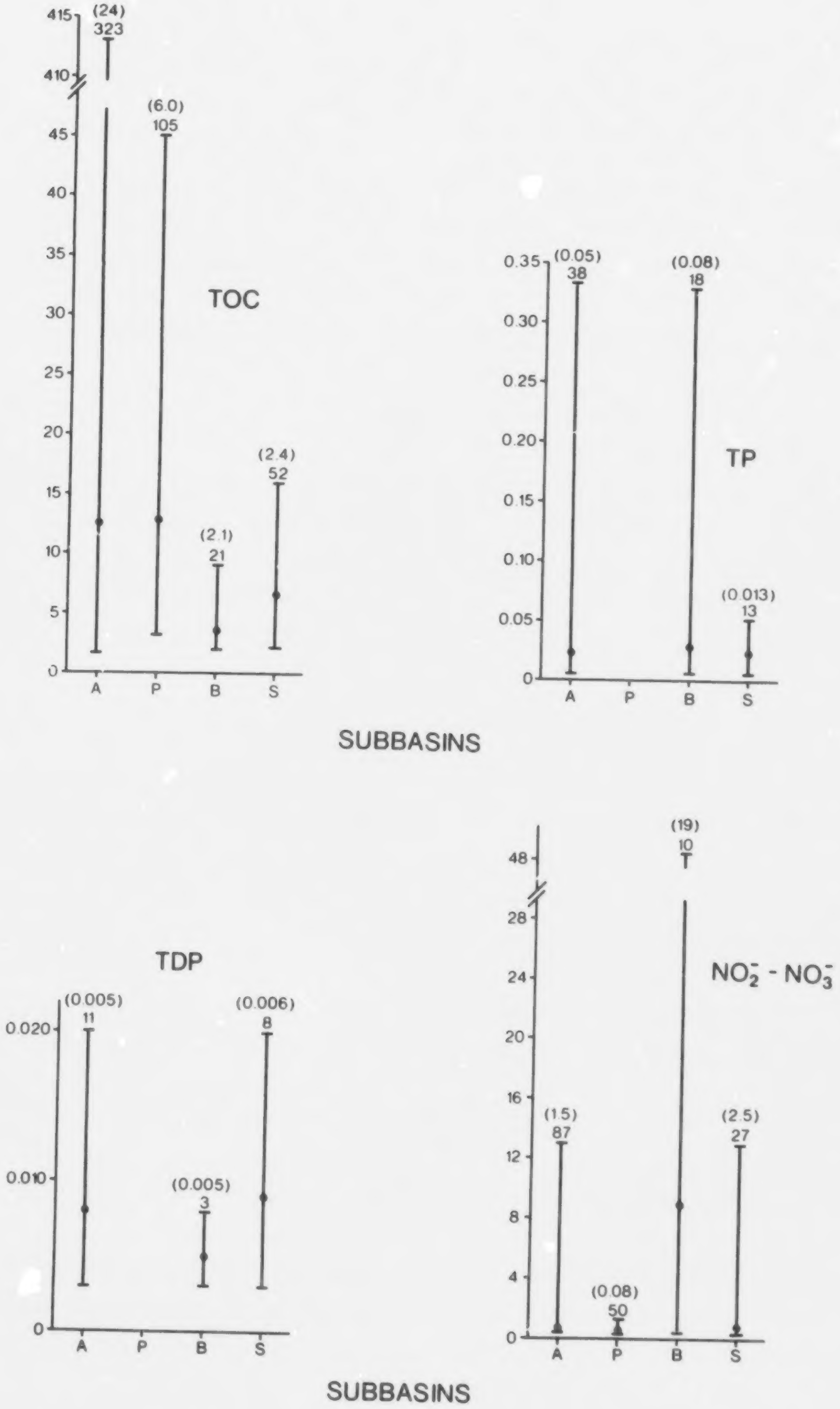


Figure 3.33 Interbasin variations in the mean nutrient concentration (mg L^{-1}) of lakes. A – Athabasca; P – Peace; B – Great Bear; S – Great Slave. Numbers indicate sample size; numbers in parentheses give standard deviation.

The Great Bear and Great Slave Lake subbasins have lower means and ranges of values of TOC than the Athabasca and Peace subbasins. This suggests relatively less terrestrial and aquatic growth in the Great Bear and Great Slave drainage basins, reflecting lower ambient temperatures and geological differences. The Peace, Great Bear and Great Slave subbasins have lower means and narrower ranges of TOC in the lakes than the rivers. The difference may be attributed to the variability in the discharge regime of rivers causing corresponding fluxes in river TOC values.

Mean TP and TDP values in the Athabasca, Great Bear and Great Slave subbasins are approximately equal. Values of TDP are similar in rivers and lakes but are more variable in rivers. The TP mean is smaller in lakes than in rivers in the Athabasca and Great Slave subbasins, and greater in the Great Bear subbasin. The relatively large amount of phosphorus associated with suspended sediments in rivers likely accounts for the former observation; the cause of the latter is unknown.

The Great Slave Lake and particularly the Great Bear Lake subbasins have equal or greater values of TP, TDP and NO_2^- - NO_3^- than the Athabasca and Peace subbasins. This has not, however, resulted in a higher mean organic content of the lake waters. Availability of the nutrient species, physical and chemical characteristics of the water and climatic factors may explain this apparent anomaly.

3.3.3 Speciation and Seasonal Variations

3.3.3.1 Nitrogen

Nitrogen occurs in the environment in various chemical forms. Elemental nitrogen is reduced by bacteria and blue-green algae to ammonia (NH_3) or ammonium ions (NH_4^+). Nitrifying bacteria convert NH_3 to the unstable nitrite (NO_2^-); another group of bacteria convert NO_2^- to nitrate (NO_3^-). Denitrification is the conversion of NO_3^- to NO_2^- and then to the gaseous N_2 form. The concentration of nitrogen species in water fluctuates, depending upon biological growth cycles, physical and chemical characteristics of the water, and the discharge regime.

Total Kjeldahl nitrogen is the sum of ammonia and ammonium ions and organic nitrogen. These compounds result from the decomposition of organic matter and the microbial reduction of NO_2^- and NO_3^- under anaerobic conditions; they are common constituents of treated sewage. Ammonia and NH_4^+ may enter a watercourse in association with clay minerals, fertilizer, decomposing organic matter, atmospheric precipitation and from industrial sources. Nitrogen is an essential plant nutrient and therefore contributes to water fertility. Organic nitrogen, also referred to as amino-nitrogen, is present in all living organisms and often can be directly incorporated into the biological community.

Dissolved nitrogen includes NH_3 and NH_4^+ as well as NO_3^- and NO_2^-. The latter compounds originate from human and animal wastes and from mineral, fertilizer and industrial sources. Nitrates stimulate plants and may cause prolific growth.

Adverse effects of the presence of nitrogen may occur in the aquatic environment. Ammonia can be toxic to fish, depending upon the concentration of undissociated ammonia and dissolved oxygen, and the pH. Toxic concentrations of NH_3 can be reached in highly alkaline waters. Manifestations of the toxicity to fish include hyperexcitment, gill hyperplasia, tissue disintegration in various organs and reduction in the oxygen-carrying capacity of the blood. A conspicuous effect of excessive quantities of nitrogen in waters is high productivity of aquatic biota. Flourishing plant growth, however, may diminish the dissolved oxygen content of the water, may cause a shift in species composition and can be aesthetically undesirable.

Nitrogen speciation was evaluated on a seasonal basis for the Athabasca River at Athabasca. This site was chosen as data were available for many of the species. Due to irregularity in the amount of data per month and the data distribution over the year, data are evaluated in seasonal groups. An examination of the hydrograph (Fig. 3.8) showed that data can be divided into groups representing winter low flow, rising spring and peak summer discharges and declining fall flows. Values in the seasonal histograms (Fig. 3.34) are averages of all data per species for each seasonal group.

Particulate nitrogen comprises the lowest proportion of the total nitrogen content over the winter period. Since winter is a low energy regime, few materials are transported in suspension. Mineralization of particulate to dissolved nitrogen forms during the low water periods may be occurring (Keeney, 1973). The total nitrogen content in spring (estimated from particulate N plus dissolved N) is higher than in other seasons due to the high concentration of particulate nitrogen, reflecting increases in discharge and suspended sediment transport, and of dissolved compounds that are mobilized from the drainage basin. The particulate and dissolved nitrogen concentration from June to November is relatively lower than in spring due to biouptake and the dilution and flushing of nitrogen compounds from the system.

The concentration of TKN remains relatively constant during the year. Dissolved organic nitrogen represents the difference between TKN and NH_3-NH_4^+. This component is at its greatest concentration

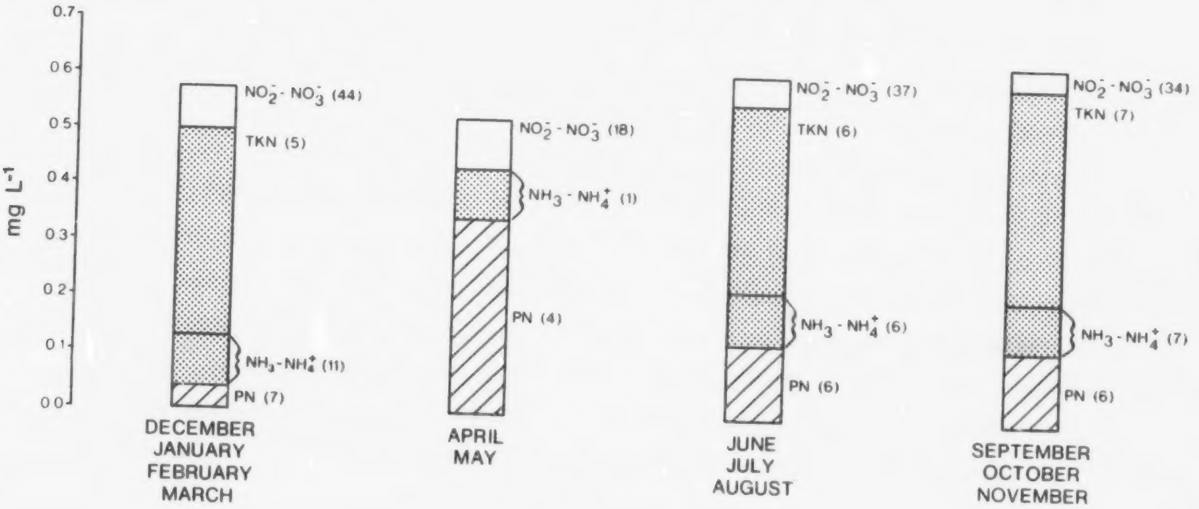


Figure 3.34 Seasonal variation of nitrogen species concentrations, Athabasca River at Athabasca. Numbers in parentheses are sample size. Notations are given in text.

over the year in the September to November period. This reflects compounds leached from decaying organic materials in the drainage basin and those from in-stream decomposition processes. Concentrations of NO_2^- - NO_3^- are slightly higher in winter and spring than in summer and fall. This likely reflects a groundwater source in winter and overland runoff of NO_3^- during rising flows in the spring (Logan, 1977), combined with biological use of NO_3^- during the period of growth in summer and fall.

The concentration of ammonia is approximately equal to (winter, spring) or larger than (summer, fall) that of NO_2^- and NO_3^-. Since the presence of dissolved organic compounds (humic compounds, tannins and other products of decomposition) inhibits the nitrification process, less NO_2^- and NO_3^- are produced, and NH_3 and NH_4^+ are accumulated (Akena, 1979; U.S Geological Survey, 1970). The U.S. Geological Survey (1970) notes that oil field brines are sometimes high in ammonia. Regions of oil development occur throughout the Athabasca subbasin. Possible ammonia contributions from resource development, combined with the presence of dissolved organic compounds, may be responsible for the higher concentrations of ammonia than of NO_2^- and NO_3^-. This represents a potential problem in the North and deserves further investigation. The elevated ammonia levels in the fall may be partly due to the release of ammonia that accompanies algal die-off, and from the mineralization of dissolved- and particulate-N (Akena, 1979). A decline in the rate of nitrification with decreasing temperatures is the primary factor.

Proportions of nitrogen species and seasonal changes at Smoky River at Watino are very similar to those at Athabasca. Absolute concentrations, however, differ. Spring and summer species concentrations, especially those of particulate -N, are approximately twofold higher in the Smoky River. This is due to the higher concentration of suspended solids in the Smoky than the Athabasca River as indicated by turbidity values (Table C-1, Appendix C).

Speciation data for nitrogen at Mackenzie River at Norman Wells suggest that NO_2^- - NO_3^- concentrations are lower in summer and fall compared with levels in winter and spring. This reflects overland runoff of NO_3^- in spring, biological utilization of NO_3^- in summer and fall and/or a decline in the rate of nitrification in the summer and fall as mentioned previously.

3.3.3.2 Phosphorus

Phosphorus is an essential element for the growth of plants. It exists in organic and inorganic forms both in solution and in association with solid material. Conversion between chemical species may be biologically or chemically mediated. Concentrations and proportions of the chemical species fluctuate over time with changes in the physical and chemical state of the medium, and with biological growth cycles.

Total phosphorus (TP) represents dissolved phosphorus and particulate phosphorus, of which the latter is not directly measured. Total dissolved phosphorus (TDP) is a measure of soluble organic and some inorganic P species. The measurement of total inorganic phosphate includes soluble and particulate species; the soluble species include dissolved inorganic phosphate and dissolved orthophosphate. Phosphorus in water originates from the weathering and leaching of mineral materials, from human wastes, industrial effluents and agricultural drainage from fertilized land.

The availability of the various chemical forms of phosphorus to biota is unclear. No single concentration measurement can estimate the biological phosphorus availability because of the multiplicity of factors involved, but the chemically determined non-apatite form (included in the analysis) is the most likely form available for biological growth. The amount of available phosphorus species is only one of many factors determining the productivity of waters. The competition for phosphorus species between biotic and abiotic components and the exchange rate of phosphorus between solid and aqueous phases are key processes in the regeneration of phosphorus in natural waters. Physical, chemical and metabolic factors determine the rate of exchange. Productivity of a water body is thus affected by regeneration processes governing the amounts of ambient phosphorus and therefore the potentially available phosphorus, as well as the phosphorus utilization strategies of the resident biota.

Phosphorus speciation was evaluated on a seasonal basis for the Athabasca River at Athabasca (Fig. 3.35). The histogram of Figure 3.35 was obtained in the same manner as the corresponding one for nitrogen species (see section 3.3.3.1). Particulate-P (calculated from TP-TDP) is a minor portion of TP during the low flow winter regime. On the rising limb of the hydrograph, particulate-P is increased by erosion and overland flow processes and mobilization of bed material. Total dissolved phosphorus also increases in concentration as soluble compounds in the basin are flushed into the aquatic system. During peak discharge, particulate-P is at its highest proportion of TP during the year; TDP concentrations are decreased by high flow dilution, adsorption of ions onto sediments and bioassimilation. Declining fall flows are paralleled by a lower TP concentration and a lesser proportion of particulate-P. Monthly variations of TP values are shown in Figure 3.36. The relationship between TP and discharge is indicated in Figure 3.37; values appear to increase exponentially with discharge.

Dissolved orthophosphate reaches its highest concentration during the spring and fall periods. This likely reflects lack of

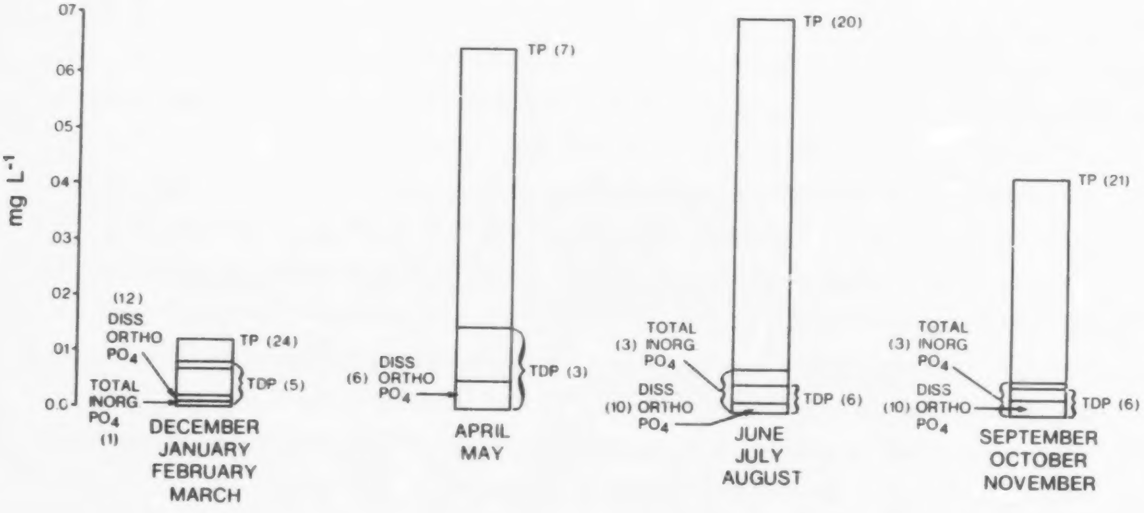


Figure 3.35 Seasonal variation of phosphorus species concentrations, Athabasca River at Athabasca. Numbers in parentheses are sample size. Notations are given in text.

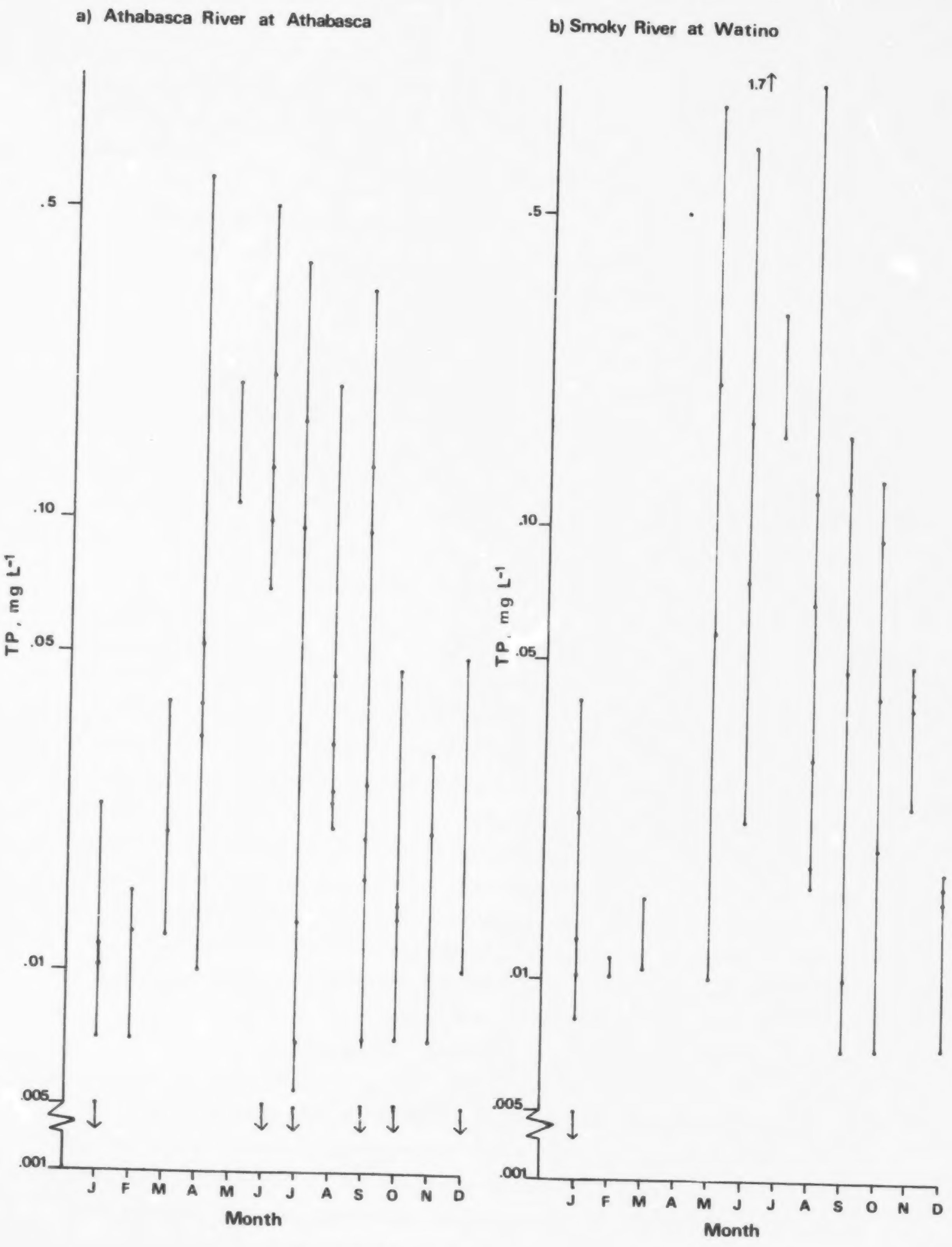


Figure 3.36 Seasonal variation of total phosphorus.

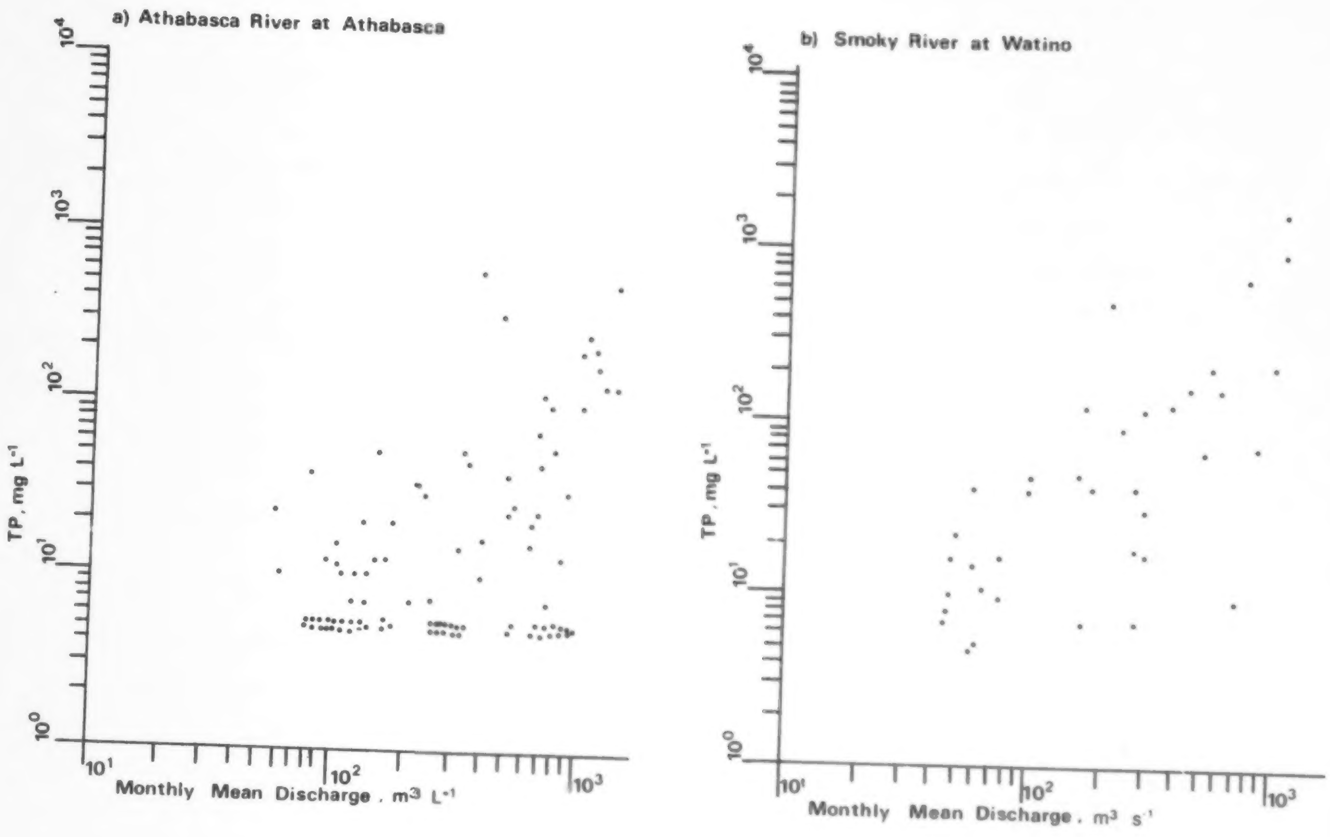


Figure 3.37 Relationship between discharge and total phosphorus.

biological activity as well as mineralization of phosphorus-containing material mobilized from the drainage basin in spring, and the release of orthophosphate from aquatic vegetation during fall senescence. The lower concentration of orthophosphate over the summer (June-August) reflects biological uptake of nutrients from the ambient waters. Dissolved orthophosphate is at its lowest concentration over the year and is a minor proportion of TDP during the winter. This contrasts with work by Akena (1979) in a small watershed in the Athabasca subbasin which indicates increases of this species under ice cover.

Seasonality of phosphorus speciation at Smoky River at Watino is similar to that in the Athabasca. Differences occur in the amount of increase in TP over the spring and summer periods. Concentrations rise between six and sevenfold in the Athabasca, whereas an order of magnitude increase occurs in the Smoky River. As the increase in TP in each case is due to the increase in particulate-P, the greater seasonal concentration change in the Smoky compared with the Athabasca reflects the greater amount of sediment in transport (section 3.1) in the Smoky River.

Phosphorus speciation in the Mackenzie River at Norman Wells shows minor change from December through August. An increase in concentration of all species in the fall (September-November) is evident, likely reflecting the contribution to the mainstem Mackenzie River of the elevated tributary nutrient levels over the summer period.

3.3.3.3 Carbon

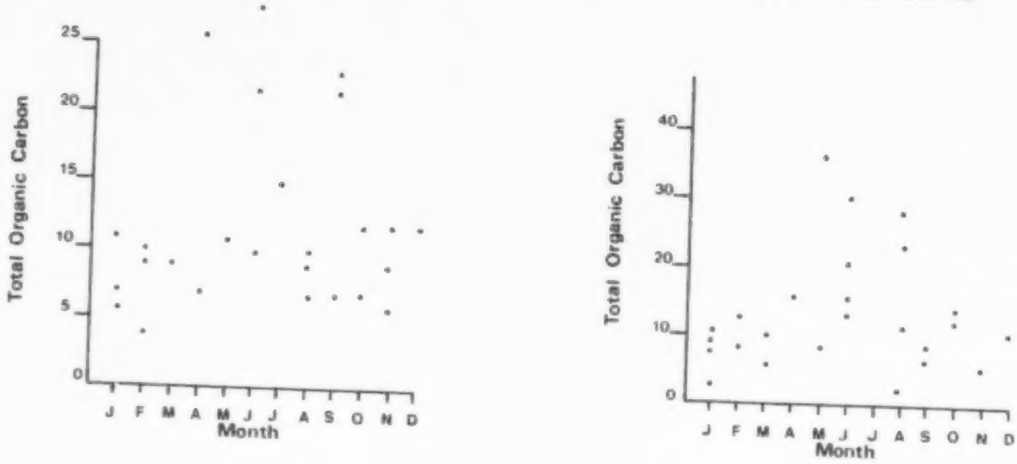
Total organic carbon (TOC) in water is composed of particulate and dissolved forms. The particulate fraction consists of suspended flora and fauna as well as fragmented and decaying organic material. Dissolved organic carbon (DOC) is composed largely of humic and fulvic substances which result from the decay of organic matter and of solutes released from photosynthetic activities.

Organic carbon has adverse as well as beneficial effects in the aquatic environment. The decomposition process of particulate organic matter consumes dissolved oxygen from the water. In large quantities, therefore, organic carbon may lower dissolved oxygen concentrations to levels below that required by aquatic organisms. Dissolved organic carbon,in the form of humic and fulvic acids, acts as a chelating agent by binding dissociated, toxic forms of dissolved metals and possibly organic contaminants. While bound, the availability of these compounds to aquatic life may be lessened.

Monthly concentrations of TOC and DOC are presented in Figure 3.38. All data for the period of record are plotted for selected sites. Although the amount of data per month and the data distribution over the year are irregular, a seasonal pattern is apparent. Total organic carbon peaks at all sites in the summer (Figs. 3.38a, b, c, d) coinciding with the period of biological productivity. Dissolved organic carbon reaches its highest values in spring and early summer at Athabasca

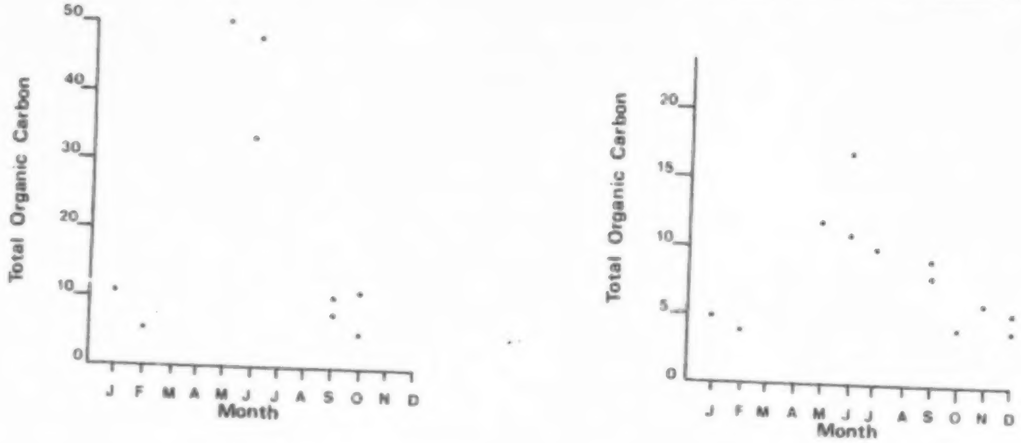
a) Athabasca River at Athabasca

b) Smoky River at Watino



c) Peace River at Peace Point

d) Mackenzie River at Norman Wells



e) Athabasca River at Athabasca

f) Smoky River at Watino

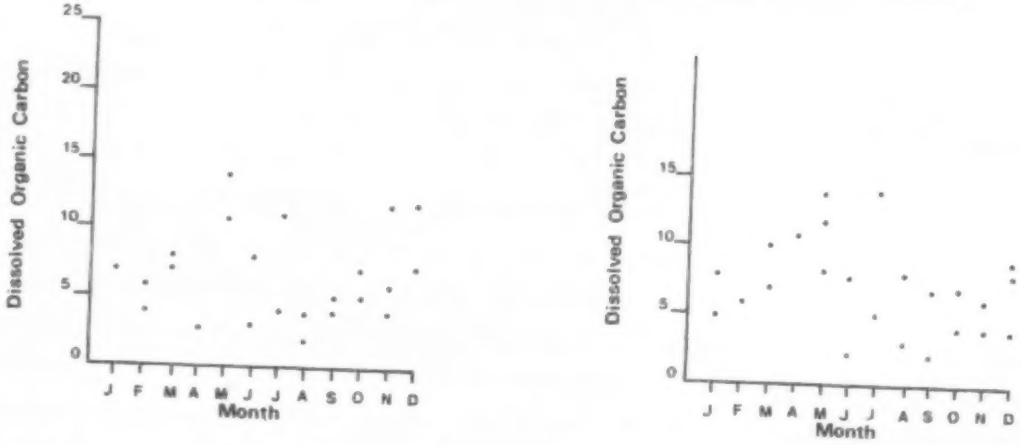


Figure 3.38 Seasonal variations of total organic carbon and dissolved organic carbon at selected sites. All values are in milligrams per litre.

and in the Smoky River (Figures 3.38e, f) as soluble organic substances are washed out of the drainage basins by surface runoff. The high proportion of the total organic content that is present in the form of DOC is noteworthy in view of the effects of DOC noted above.

3.3.4 Spatial Variations

Intrabasin variations in nutrient concentrations reflect differences in the physical characteristics of the water, geology, natural inputs and the discharge regime. Evaluation of the variations is limited by the lack of data for several nutrient species. Error may be introduced in the concentration comparisons by the highly variable sample size for species at the selected sites.

Variations in nitrogen, phosphorus and carbon species concentrations in the Athabasca River subbasin are shown in Figure 3.39a. The lowest values of the nutrients occur at the headwaters (upstream from Sunwapta) and in the Fond du Lac River in the Shield region. The particulate-related species (TP, TOC) increase in concentration and in range at Athabasca and Fort McMurray; this is a pattern parallel to that of turbidity. Dissolved nutrient species have a narrower range of values; $NO_2^- - NO_3^-$ shows no apparent downstream trend, whereas mean values of TKN increase slightly downstream. The relatively high mean values and ranges of TP, TKN and TOC at Fort McMurray may reflect resource development activities or natural variations in nutrient supply and use along the mainstem Athabasca River.

Few trends are evident in the Peace River subbasin data (Fig. 3.39b). The mean value and range of TKN, $NO_2^- - NO_3^-$ and TOC increase downstream in the Peace River. Mean values for the nutrient species in the Smoky River approximate those for the Dunvegan site on the Peace River.

Nutrient concentrations at selected sites in the Liard River subbasin (Fig. 3.39c) are similar in mean values but increase in range down the Liard mainstem. The TP mean is distinctly higher upstream from

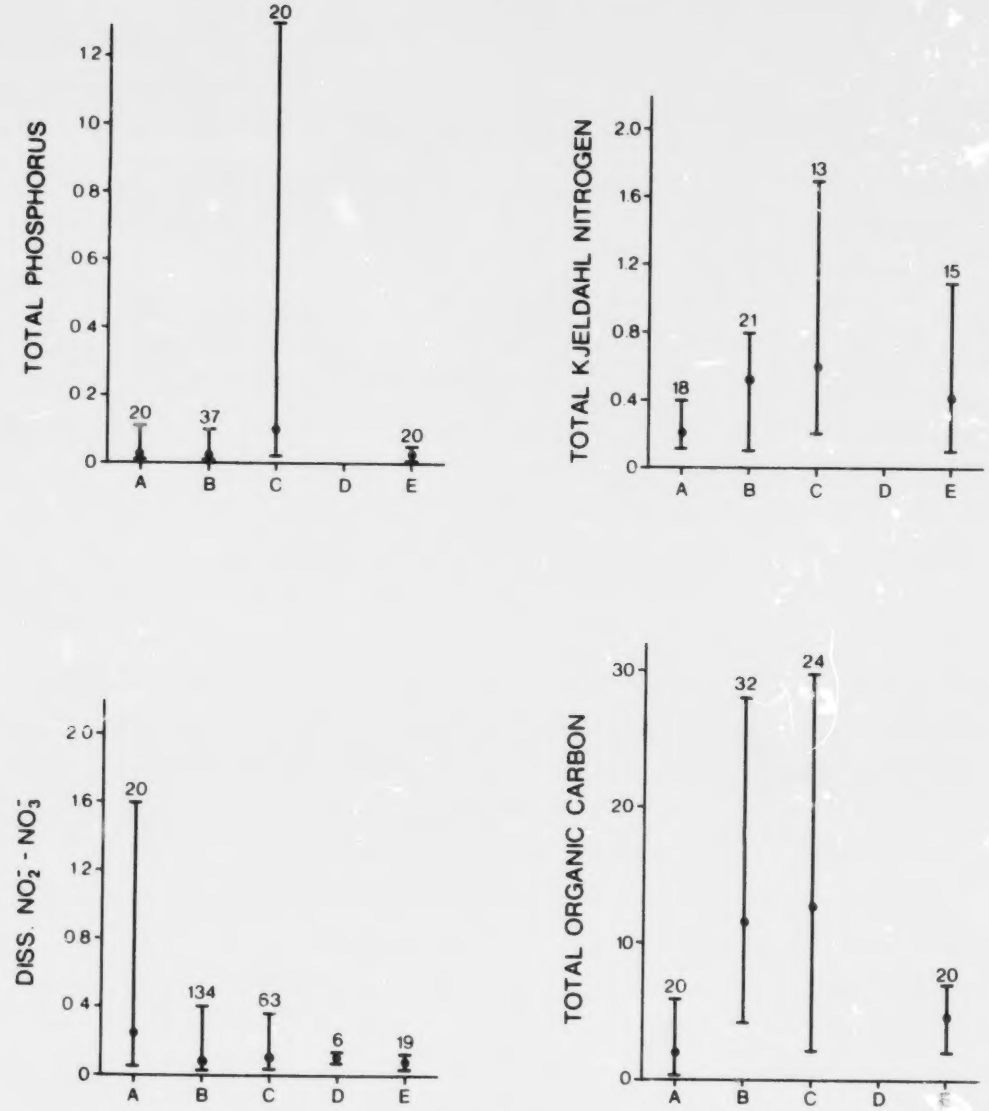


Figure 3.39a Spatial variation of nutrient parameters at selected sites in the Athabasca River subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – upstream from Sunwapta; B – at Athabasca; C – at Fort McMurray; D – at Bitumount; E – Fond du Lac River.

Fort Simpson than at other sites in the basin; turbidity in the river also peaks at this site (Table C-1c, Appendix C). The South Nahanni River has higher values of NO_2^- - NO_3^- and lower values of TOC than the Liard River, suggesting relatively less in-stream productivity in the South Nahanni.

Figure 3.39d illustrates regional differences in the Great Slave Lake subbasin. The Lockhart River, draining the Shield area, has lower

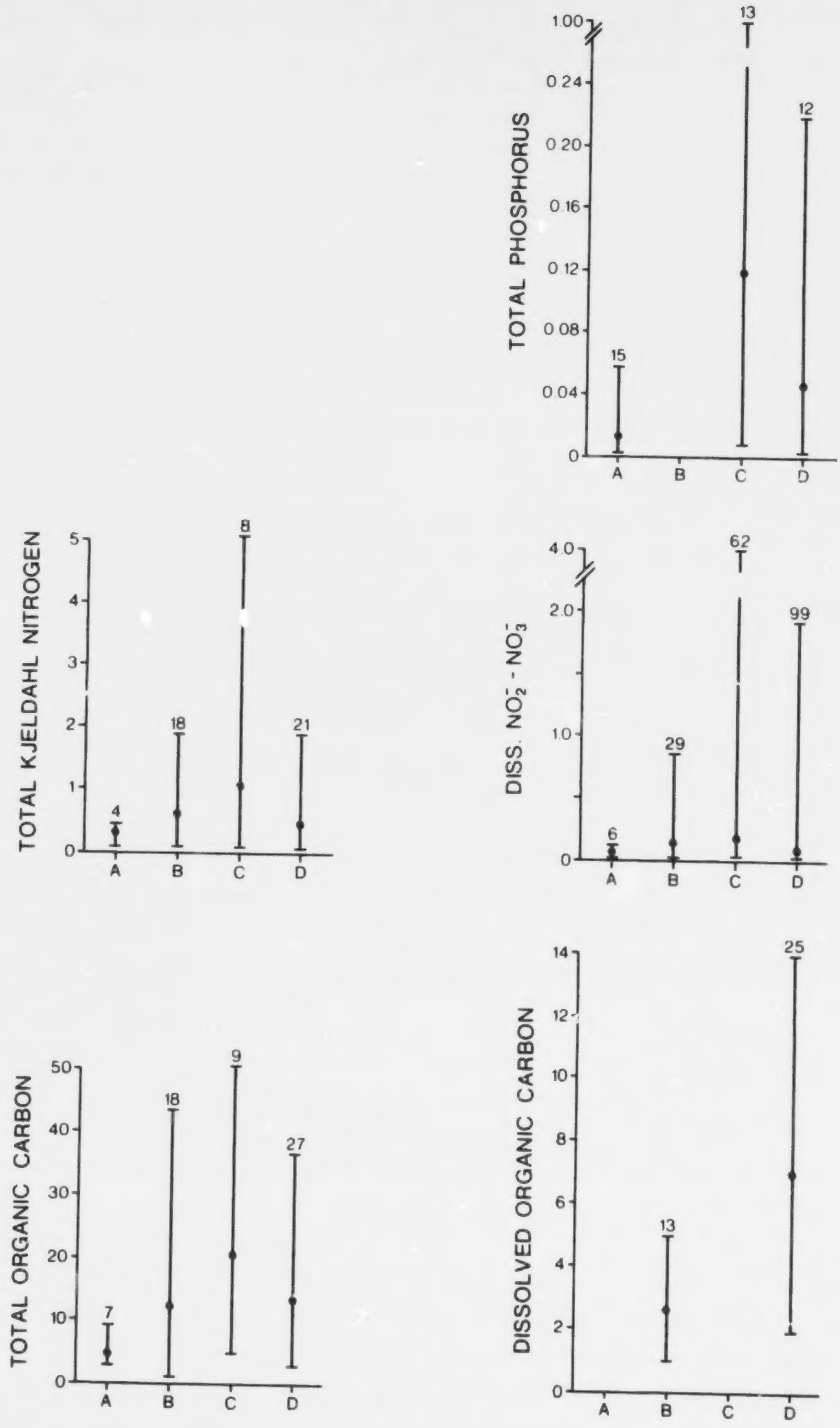


Figure 3.39b Spatial variation of nutrient parameters at selected sites in the Peace River subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – at Hwy. 29; B – at Dunvegan; C – at Peace Point; D – Smoky River at Watino.

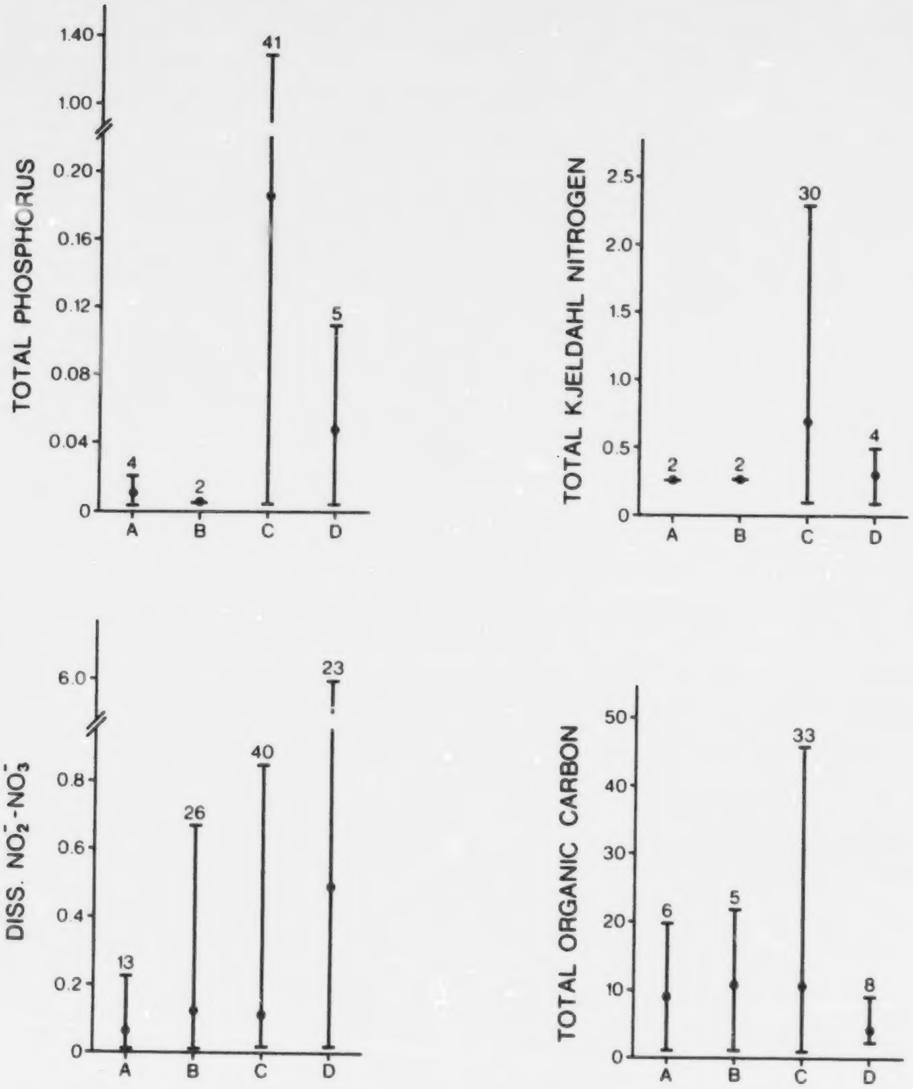


Figure 3.39c Spatial variation of nutrient parameters at selected sites in the Liard River subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – upstream from Dease River; B – at Fort Liard; C – upstream from Fort Simpson; D – South Nahanni River.

means of TP, TKN, NO_2^- - NO_3^- and TOC than the Slave River and Yellowknife Bay. The Slave River has relatively higher means and ranges of TP and TOC, reflecting the high turbidity and colour values and variable discharge resulting from the combined flows of the Athabasca and Peace rivers (Tables C-1a, b, Appendix C). Yellowknife Bay has higher means

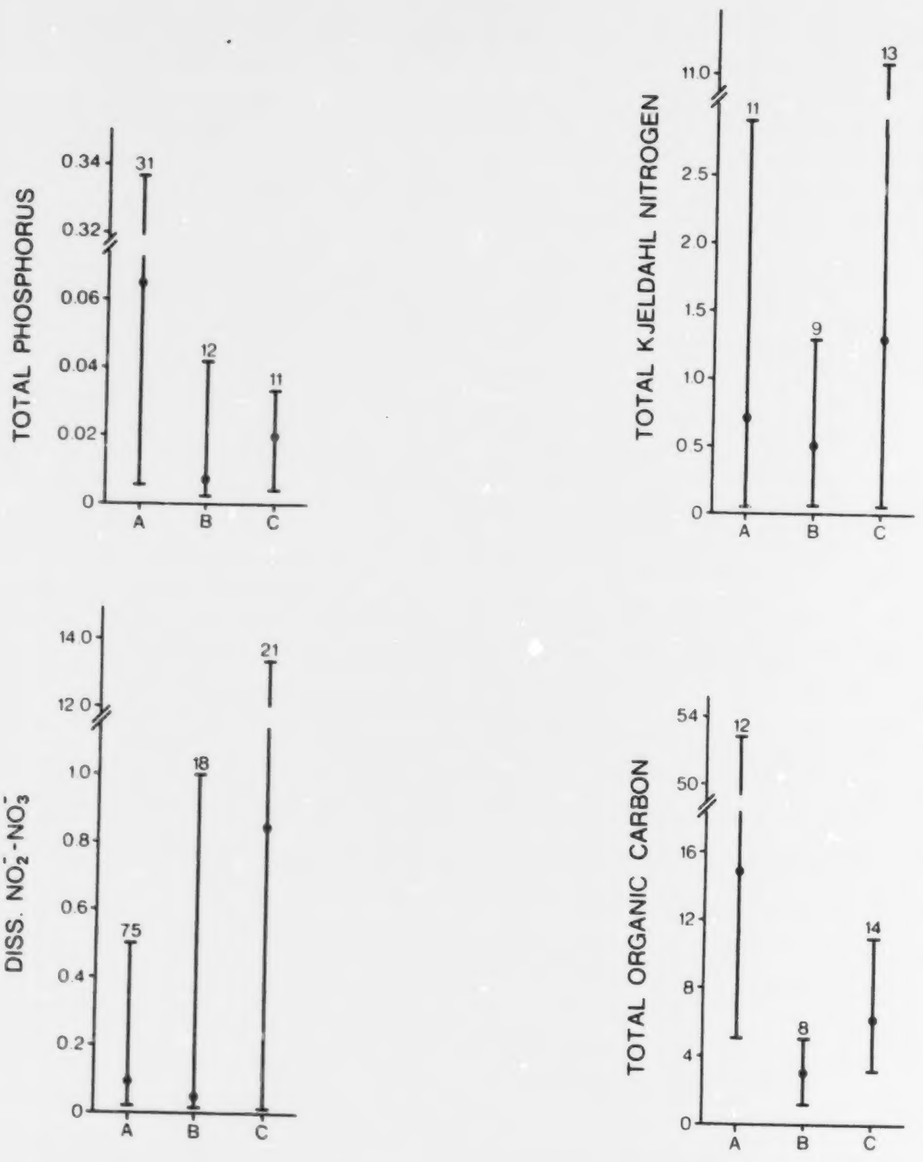


Figure 3.39d Spatial variation of nutrient parameters at selected sites in the Great Slave Lake subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – Slave River at Fitzgerald; B – Lockhart River; C – Yellowknife Bay.

and a broader range of values of TKN and NO_2^- - NO_3^- than those for the rivers; values are likely biased for the lake by the shallow sampling location in the Bay and the effects of sewage effluent and storm runoff from Yellowknife and effluent from Giant Mine.

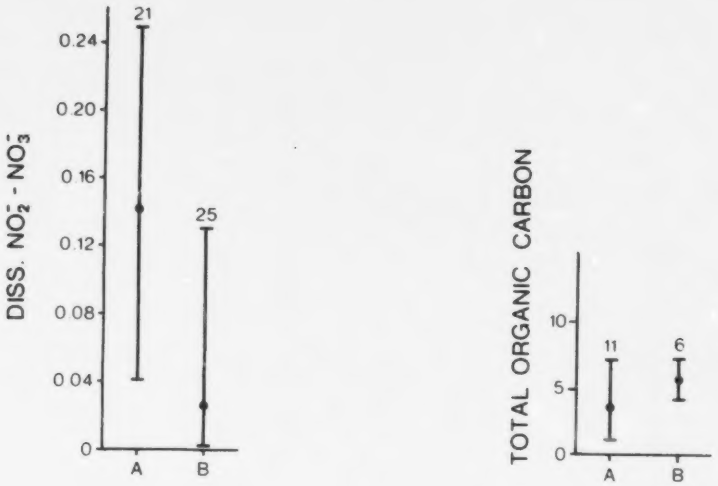


Figure 3.39e Spatial variation of nutrient parameters at selected sites in the Great Bear Lake subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – Great Bear Lake outlet; B – Camsell River.

The Great Bear Lake subbasin contains low levels of nutrients (Fig. 3.39e). The mean concentration of NO_2^- - NO_3^- is much greater in the Great Bear River at the lake outlet (0.141 mg L^{-1}) than in the Camsell River (0.026 mg L^{-1}). The former value, as expected, is identical with the mean concentration in the lake. The TOC values at the selected sites are very similar.

Spatial trends of nutrients in the Mackenzie River subbasin (Fig. 3.39f) appear to reflect turibidity variations and the influence of Great Bear Lake. Mean values of TOC (and possible TP) parallel those of turbidity (Table C-1, Appendix C). Values of TDP, TKN and NO_2^- - NO_3^- may be affected by input from Great Bear River. For example, TDP near Wrigley (0.003 mg L^{-1}) may be increased by Great Bear River (0.029 mg L^{-1}) inputs to produce a value of 0.007 mg L^{-1} at Norman Wells. Similarly, the concentration of NO_2^- - NO_3^- in the river (0.144 mg L^{-1}) may be partly responsible for the higher concentration at Norman Wells (0.181 mg L^{-1}) compared with that at Wrigley (0.088 mg L^{-1}). Natural variations along the course of the river and from the many tributaries of the Mackenzie River are probably largely responsible for the spatial variations.

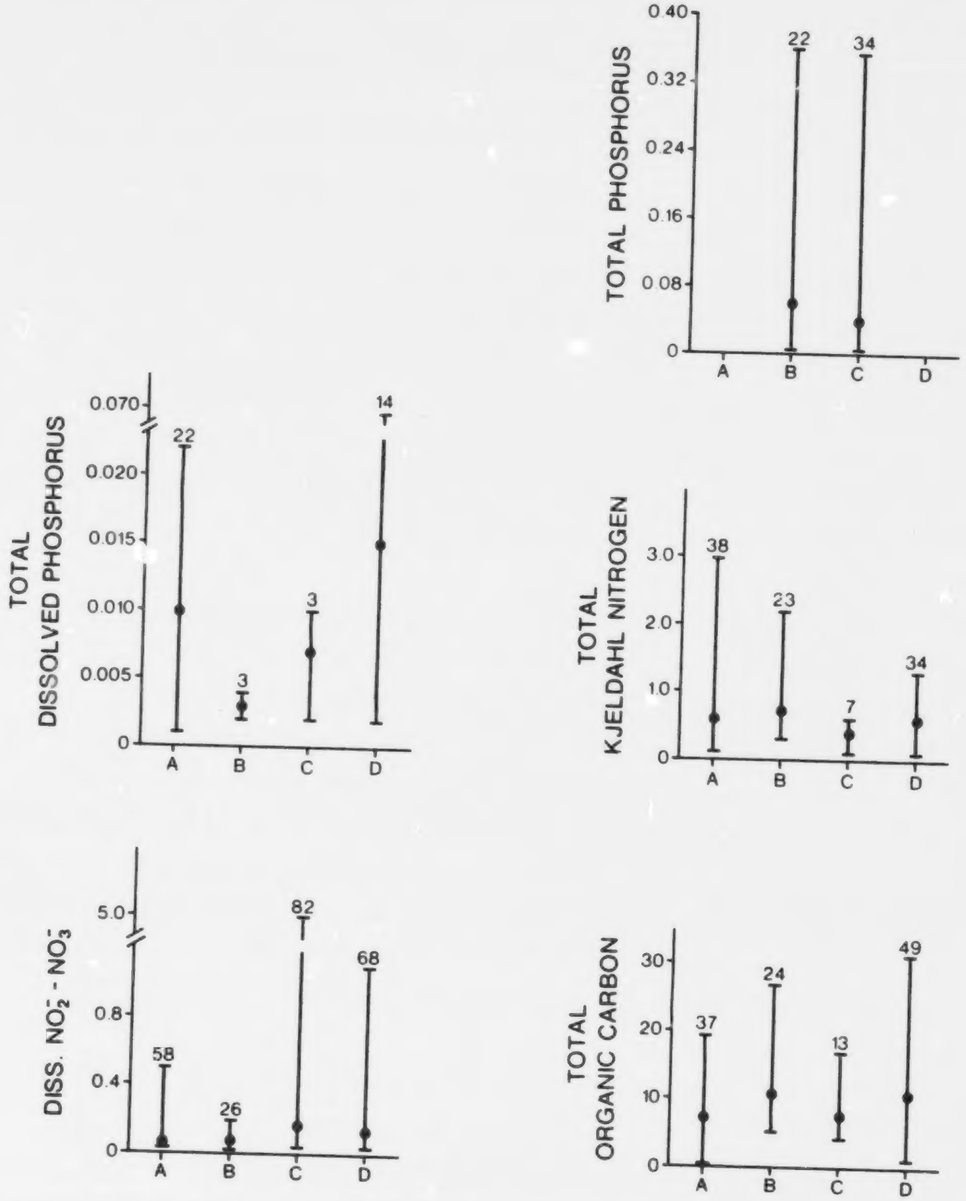


Figure 3.39f Spatial variation of nutrient parameters at selected sites in the Mackenzie River subbasin. Minimum, mean and maximum values (mg L^{-1}) are presented. Numbers indicate sample size. A – at Fort Providence; B – near Wrigley; C – near Norman Wells; D – upstream from Arctic Red River.

3.3.5 Time Trends

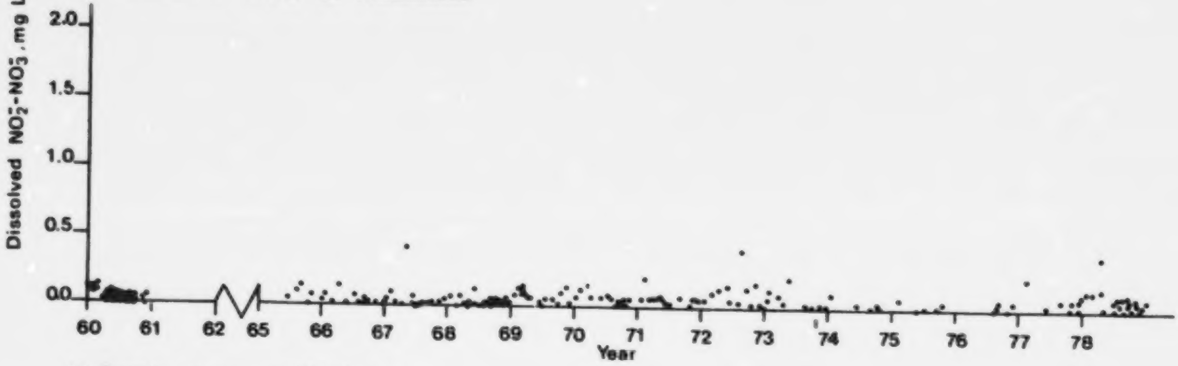
To identify changes in nutrient concentrations over time, concentrations at sites with long, continuous periods of record were examined. Total phosphorus and NO_2^- - NO_3^- were selected, as these are the only nutrient species with sufficient and appropriate data to merit time trend analysis.

Time plots for concentrations of $NO_2^- - NO_3^-$ at Athabasca River at Athabasca, Smoky River at Watino, Peace River at Peace Point and Mackenzie River at Norman Wells are shown in Figure 3.40. A variety of analytical methods were used over the period of record; all may not be directly comparable. Variability is greater in some years than in others, for example, 1972 at all sites and 1967 and 1978 at Athabasca and Smoky rivers. However, concentrations at each of the sites are almost all less than 0.5 mg L^{-1} and on a visual examination show no trend over the period of record.

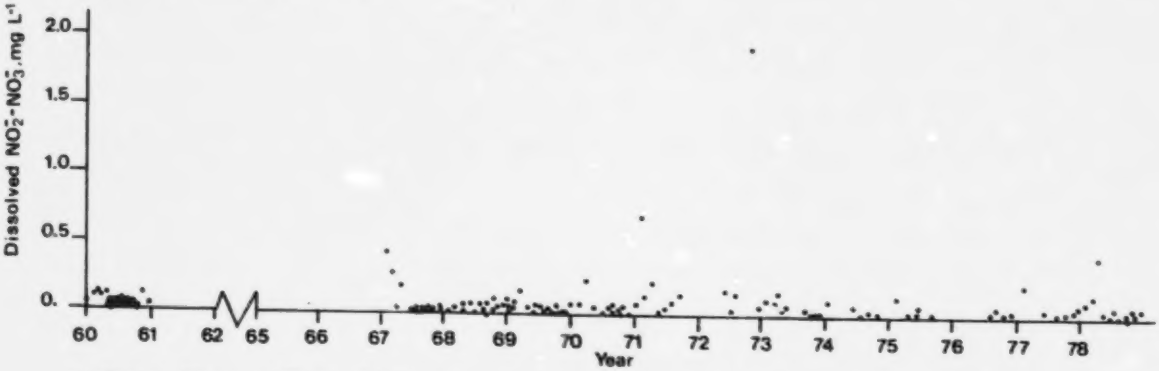
Time plots for concentrations of TP in the Athabasca, Smoky, Peace and Mackenzie rivers are illustrated in Figure 3.41. Difficulty in ascertaining real changes in concentration arises due to changes in analytical techniques and associated changes in detection limits, as well as a change in laboratories, over the period of record. For example, a method change occurred in 1974, after which time TP in the Athabasca and Smoky rivers appears to increase in concentration and variability. The techniques employed are based upon similar chemical reactions; the difference between the methods is the use of a different reducing agent in the 15413L method that permits a lower limit of detection (0.001 mg L^{-1}) for 15413L and 0.003 mg L^{-1} (for 15406L). Difficulties in distinguishing between concentrations around the detection limit are complicated by different data records showing conflicting detection limits. Because of the analytical uncertainties, the TP concentration increase in the Athabasca and Smoky rivers from 1973 to 1979, compared with the time period 1969-1970, may not be real. Although sparse, the data suggest a similar pattern at Peace River at Peace Point (Fig. 3.41c). There is no discernible TP concentration change from 1960 to 1979 in the Mackenzie River at Norman Wells (Fig. 3.41d).

It is expected that any observed changes in concentration of the nutrient parameters over time are reflections of the methodological history of the data rather than actual changes in the quality of the water.

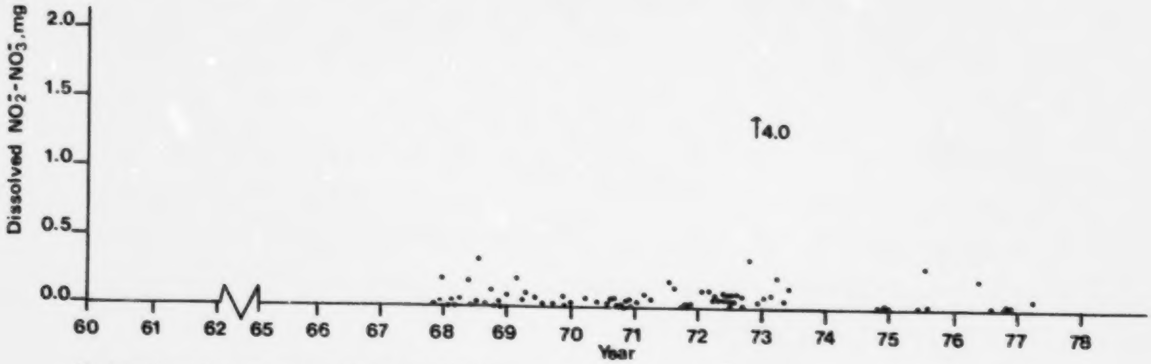
a) Athabasca River at Athabasca



b) Smoky River at Watino



c) Peace River at Peace Point



d) Mackenzie River at Norman Wells

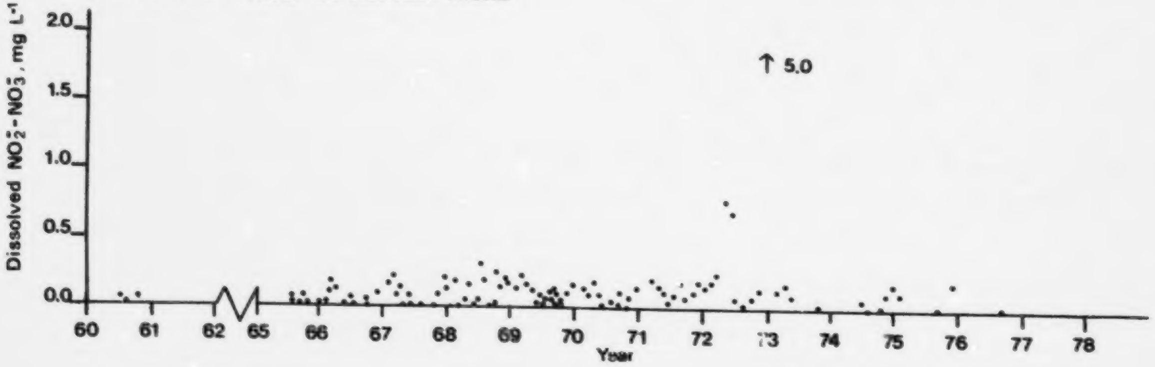
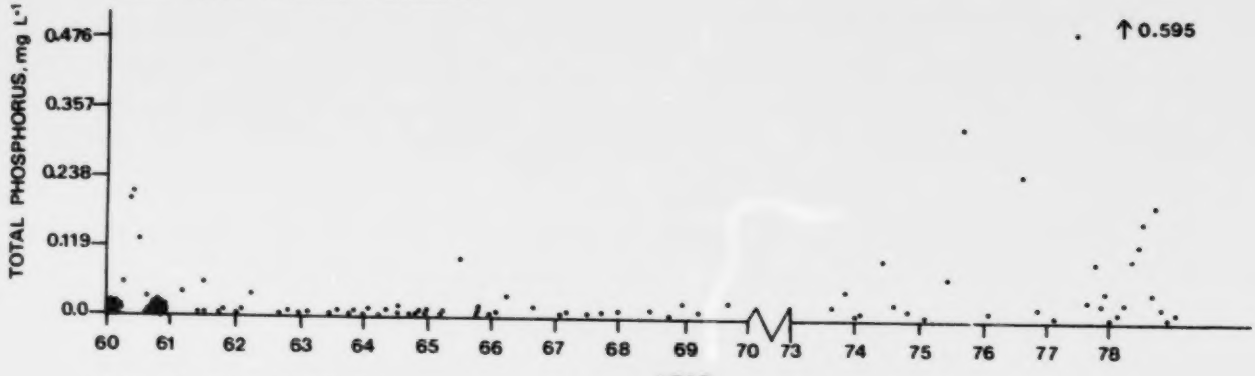
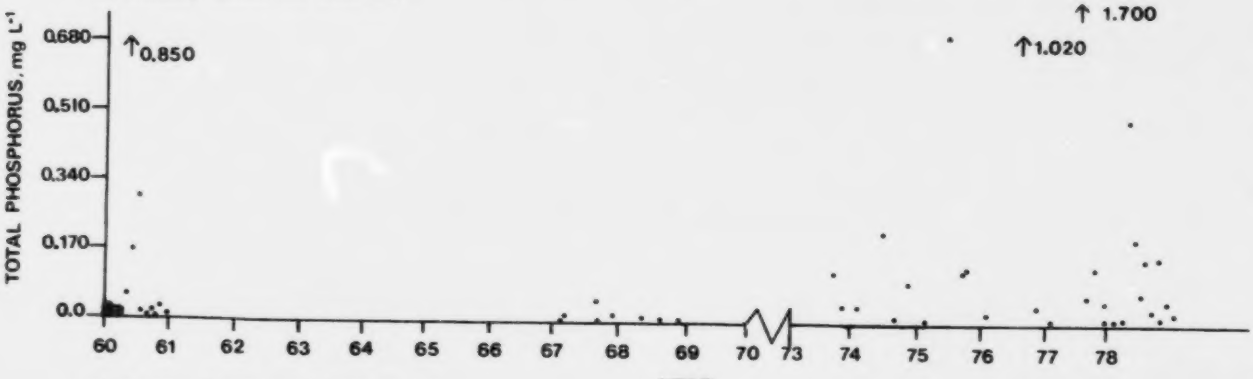


Figure 3.40 Variation in dissolved NO_2^-–NO_3^- over time (1960–1979) at selected sites.

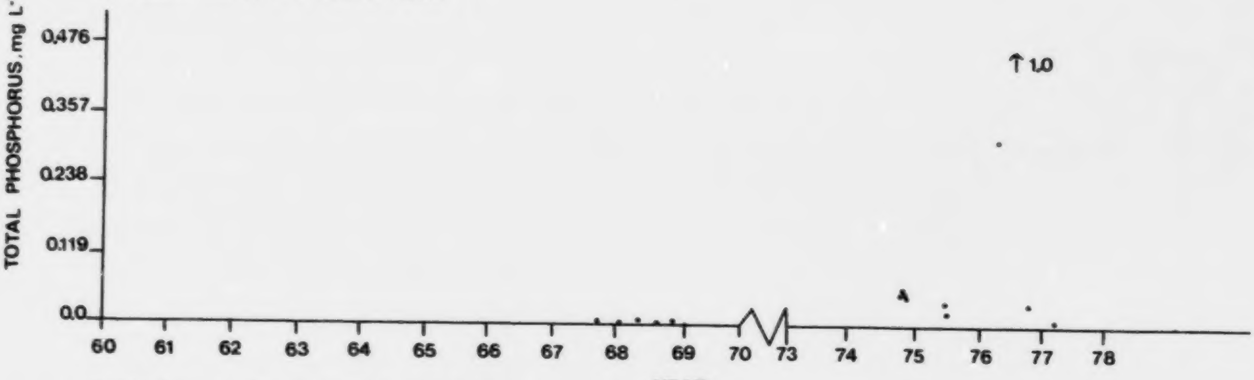
a) Athabasca River at Athabasca



b) Smoky River at Watino



c) Peace River at Peace Point



d) Mackenzie River at Norman Wells

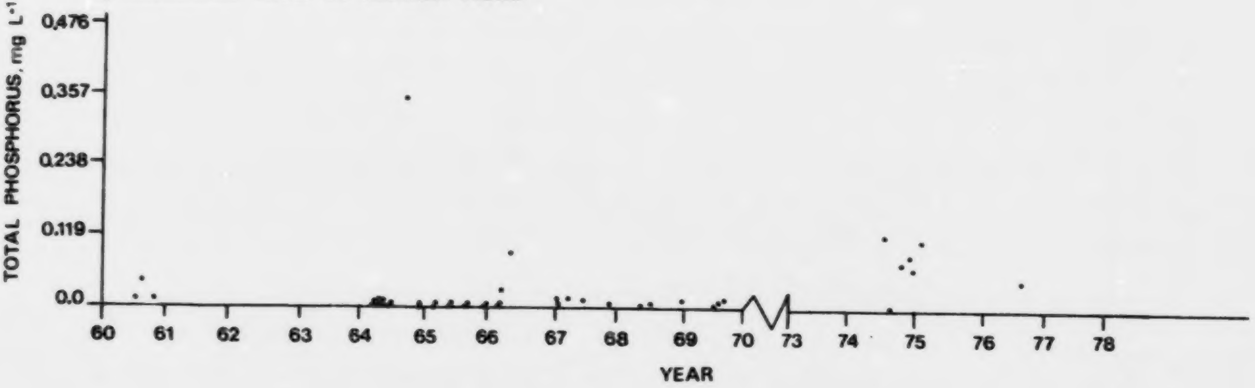


Figure 3.41 Variation in total phosphorus over time (1960–1979) at selected sites.

3.3.6 Comparison of Subbasin and Selected Site Means

Table 3.6 subjectively expresses the proximity of the site nutrient mean (Table E-1, Appendix E) to the subbasin mean (Table 3.5). The following sites have means which approximate, within 15% or 25%, the respective parameter subbasin means: Athabasca, Smoky River at Watino, Fort Simpson, Hay River, Camsell River, Slave River at Fitzgerald and Wrigley. For example, the Athabasca site characterizes, within 15% or 25%, the mean values of dissolved N, TKN, TDP and DOC for the Athabasca subbasin. It is of interest to note that several of these sites are different from those that approximate the physical parameter and major ion subbasin values. This highlights the different spatial behaviour of the physical, ion and nutrient parameters in the various subbasins.

Total organic carbon and TKN are the nutrient parameters which most frequently show similar values for the sites and subbasins; dissolved N, DOC and TP means are the least frequently similar. The comparison indicates the spatial variability of the parameters within and between the subbasins.

3.3.7 Conclusions

Variations in nutrient concentrations between the subbasins reflect physiographic subdivisions of the Mackenzie Basin. Seasonal variations in concentrations of nitrogen and phosphorus species parallel suspended sediment and discharge regimes in the rivers and biological utilization patterns. The greater variability of nutrient levels in rivers than in lakes is also attributed to the physical regimes. Organic carbon variations are due to biological growth cycles and physical processes in the drainage basin.

Spatial variations in the subbasins are attributed to physical and geological changes along the course of the rivers. Anthropogenic effects are not evident in the available data. Changes in nutrient concentrations over the period of record are likely due to analytical changes but may be due to natural and/or anthropogenic causes.

Table 3.6 Comparison of Subbasin and Selected Site Means - Nutrient Species

Subbasin, selected site	Nitrogen				Phosphorus		Carbon	
	Dissolved nitrogen	Dissolved NO_2^-	Dissolved NO_3^-	TKN	TDP	TP	Dissolved organic	Total organic
Athabasca								
Upstream from Sunwapta								
At Athabasca	(✓)			✓	(✓)		(✓)	
At Fort McMurray								
At Bitumount								
Fond du Lac River				✓				
Peace								
At HWY 29	✓							
At Dunvegan								✓
At Peace Point				✓				
Smoky River at Watino	(✓)	✓			✓		✓	✓
Liard	N.D.				N.D.		N.D.	
Upstream from Dease River								✓
At Fort Liard		✓						
Upstream from Fort Simpson		(✓)		✓				
South Nahanni River								
Hay	N.D.				N.D.		N.D.	
Hay River at mouth		✓		✓		✓		✓
Great Bear	N.D.					N.D.	N.D.	
Great Bear Lake at outlet				✓				
Camsell River				✓	✓			✓
Great Slave	N.D.				N.D.		N.D.	
Slave River at Fitzgerald				✓		✓		✓
Lockhart River				✓				
Yellowknife Bay								
Mackenzie							N.D.	
At Fort Providence				✓				
Near Wrigley				✓	✓	(✓)		✓
Near Norman Wells		(✓)						
Upstream from Arctic Red River		✓		✓				✓

✓ = Selected site mean closely approximates subbasin mean (within 15% of value).
(✓) = Selected site mean in vicinity of subbasin mean (within 25% of value).
N.D. = No data for this parameter at selected sites in this subbasin.

Variations in nutrient concentrations in the Mackenzie Basin are not manifested in biological productivity. The availability of the nitrogen and phosphorus species required for growth, along with factors including seasonal supply, oxygen concentrations and ambient temperatures, plays a role in determining the productivity of the waters. Nutrients entering Great Bear Lake, for example, are largely associated with mineral material; they are therefore not immediately available for biological uptake and are not likely to be transformed to an available form upon deposition and incorporation into bottom sediments.

Interpretation of the nutrient dynamics is hindered by the quality of the data. Seasonal variations and relative species proportions are difficult to assess due to noncontinuous data for the individual species at each site and over each year. Evaluation of spatial variations is also limited by the inconsistency of species sampling at sites within each subbasin. All data comparisons, i.e., at each site, between sites and subbasins, and over time, are impeded by the change in laboratories and in analytical techniques over the period of record.

3.4 Metals

3.4.1 Introduction

Metals comprise a group of water quality parameters that can pose a threat to the health of the ecosystem. The concern over metals in the aquatic environment relates to the toxicity of metals to organisms, the potential for bioaccumulation in the food chain and hazards to human health. Metals originate from natural as well as anthropogenic sources. The latter include atmospheric emissions, industrial and domestic effluents and agricultural runoff.

The impact of metals upon the aquatic environment is determined by their availability to aquatic life. Physiochemical characteristics of the metals in the dissolved and solid-associated phases and chemical properties of the water influence the toxicity of the metals. The uncomplexed ion is the most important form of biologically toxic metal (Jenne and Luoma, 1977). A large proportion of many of the trace elements found in solution in natural waters exists in complexed form. Complexation, by organic or inorganic ligands, may increase or decrease the availability of the element for assimilation. For example, organic copper complexes increase the availability of the element by maintaining it in the soluble phase when copper is present at low concentrations, but decreases its availability when present at higher concentrations (Singer, 1977).

The availability of metal associated with the solid phase varies among solid forms and for a given solid form among elements. Metals incorporated in the crystal lattice of minerals are unavailable, while those associated with hydroxides and organic material are available (Gibbs, 1973, 1977). Assimilation by biota of ingested solid forms is slow relative to the uptake rate of solute species of equal concentration. Sediment-associated metals interchange with the solute phase by sorption, precipitation, and complexation reactions under varying physical and chemical conditions in the water medium. Sediment-related metals are of biological importance, therefore, not only as direct sources of metals but also as regulators of the concentration of the more readily available elements in the solute phase.

Many metals are required physiologically by aquatic organisms. Accumulation of the metals in concentrations exceeding biological requirements, however, may have direct or indirect toxic effects on the organism. Excessive quantities of metals in organisms may impair reproduction and retard the growth and maturation of juveniles. Shorter life spans of the exposed organisms, decreased viability of populations and reduced species diversity have adverse effects on the ecosystem.

A major concern of metal presence in the aquatic environment and consequent accumulation by the flora and fauna is the magnification of the metal concentrations in the food web. The upper trophic levels, which include man, may thus receive highly elevated concentrations of metals that may only have been present in aqueous form at barely detectable or undetectable concentrations. Human exposure to high metal levels may cause neurological and physiological impairment and, in some extreme cases, death.

The metals analyzed in the Mackenzie River basin and discussed here are extractable silver (Ag), aluminum (Al), barium (Ba), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), strontium (Sr), thallium (Tl), vanadium (V) and zinc (Zn). Dissolved levels measured for these metals as well as for the elements arsenic (As), boron (B) and selenium (Se), and total, extractable and dissolved levels of mercury (Hg) are not reviewed due to uncertainties of the values arising from handling and analytical problems discussed in Chapter 2.

3.4.2 Mean Values for the Subbasins

Mean values of extractable metals for the subbasins are presented in Table 3.7. Means are used as subbasin values as it is desirable to include metal concentration extremes. It is recognized that many of the means may be greatly influenced by the presence of a large number of concentrations below the detection limit. For this reason the median value is also considered in the subbasin comparisons. Since the detection limits were treated at face value, the mean values expressed are maximum values where values below the detection limit are included in the calculation. Differences in metal concentrations between the subbasins reflect regional variations in geology and the physical and chemical characteristics of the waters.

3.4.2.1 Rivers

Mean concentrations of extractable metals in rivers show natural variation between subbasins (Table 3.7). The highest values of Co, Cr, Ni and V occur in the Liard subbasin; the lowest values of Ag, Al, Ba, Fe, Mn, Ni and Zn occur in the Great Bear Lake subbasin. Consideration of metal median values (Table E-2, Appendix E) reveals that the Liard has the greatest number of metals present at concentrations above detection (17) and that the Great Bear subbasin has the lowest number of metals at detectable levels (8). The remaining subbasins contain from 13 to 15

Table 3.7 Mean Values of Extractable Metals in Mackenzie River Subbasins

Subbasin	Athabasca	Peace*	Hay	Liard	Great Bear	Great Slave	Mackenzie
Rivers							
Ag	0.01	0.01	0.01	0.009	<0.003	-	0.011
Al	1.09	1.47	0.41	0.69	0.09	0.82	0.29
Ba	0.11	0.12	0.09	0.09	0.07	0.08	0.08
Cd	0.001	0.001	0.001	0.002	0.002	0.013	0.001
Co	0.005	0.005	0.004	0.007	0.003	0.002	0.003
Cr	0.012	0.01	0.01	0.014	0.011	<0.01	0.011
Cu	0.006	0.006	0.004	0.010	0.017	0.007	0.007
Fe	2.04	2.25	2.47	1.97	0.18	2.12	2.30
Mn	0.105	0.105	0.07	0.07	0.01	0.06	0.07
Mo	0.06	0.06	0.05	0.06	<0.05	<0.10	0.06
Ni	0.008	0.008	0.009	0.02	<0.01	0.007	0.008
Pb	0.004	0.004	0.003	0.006	0.004	0.005	0.006
Sb	0.33	0.34	0.35	0.088	-	-	-
Sr	0.19	0.19	0.15	0.16	0.15	0.06	0.42
Tl	0.16	0.16	0.16	<0.001	-	-	<0.10
V	0.03	0.04	<0.05	0.06	0.04	0.01	0.05
Zn	0.012	0.013	0.008	0.02	0.006	0.02	0.02
Lakes							
Ag	0.009				0.006	-	
Al	<0.10				-	-	
Ba	<0.10				-	-	
Cd	0.001				0.001	0.001	
Co	0.005				0.006	0.002	
Cr	<0.01				<0.011	0.013	
Cu	0.024				0.03	0.033	
Fe	0.09				0.10	0.07	
Mn	0.089				0.02	0.012	
Mo	0.088				0.09	<0.10	
Ni	0.013				0.012	0.013	
Pb	0.007				0.010	0.007	
Sr	0.023				-	-	
Zn	0.021				0.015	0.026	

*No metal analyses were performed on Peace River subbasin lake water.

NOTE: Units are in milligrams per litre.

metals at detectable median concentrations. Generally, low levels of metals in the Great Bear reflect the erosion-resistant igneous Precambrian Shield rock underlying much of the subbasin; the bedrock yields low levels of mineral material with its associated metal content. The presence of a large number of detectable median concentrations in the Liard and the relatively higher magnitude of the mean concentrations reflect the diverse sedimentary geology of the watershed and the relatively high turbidity of the subbasin rivers.

3.4.2.2 Lakes

The suite of elements analyzed in river water were also analyzed in lake water. Only minor variations of mean metal concentrations exist between subbasins (Table 3.7), reflecting the geological diversity.

Comparison of river and lake mean values for the subbasins reveals that lake values are lower than or approximately equal to river values. Examination of the median values (Table E-2, Appendix E) reveals that considerably fewer metal median concentrations are at levels above detection in lakes than in rivers. The lower concentrations of metals in lakes than in rivers is directly attributed to the lesser concentration of suspended sediment (measured as turbidity, Table 3.1) in lake water, suggesting rapid sedimentation, and are similar to observations on TP in the Mackenzie system. Although suspended sediments are continually being added to lakes from feeder rivers, much of the sediment is deposited upon entering the lake and becomes incorporated into the bottom sediment. Metals associated with bottom sediment are not measured by the total extractable metal analysis. The Athabasca, Great Bear and Great Slave lakes play an important role in the Mackenzie drainage system as areas of deposition of suspended sediment, thereby reducing the suspended load of the rivers and contributing relatively sediment-free water (therefore relatively low concentration of solid-associated metals) to the mainstem Mackenzie River.

Mean concentrations of Cu in lakes are up to fourfold greater than, and those for Zn are about twice as large as, comparable values in rivers. The higher values in lakes may reflect accumulation of these elements by algal populations.

Due to the natural origin of many metals in the subbasins, the metals are not expected to be immediately available in the rivers but may be potentially available following deposition in receiving water bodies.

3.4.3 Speciation

Metals exist in fluvial systems in various associations within the aqueous and with the particulate fractions. The source and chemical characteristics of the metals and the prevailing physicochemical conditions determine the forms of metals in the river and therefore their bioavailability and subsequent impact upon the aquatic ecosystem.

Two methods used in routine metal analyses conducted in Water Quality Branch laboratories quantify metals as "dissolved" (obtained by analyzing water passed through a 0.45-µm filter) and "extractable" (analysis of an acidified, unfiltered sample) fractions. The dissolved fraction includes free metal ions, those in solution as complexes and in association with colloidal material. For example, fulvic and humic acids and humins form stable metal complexes in solution. The extractable fraction usually includes metals in the dissolved state as well as part of the metal associated with particulate matter. In the particulate form, metals may be incorporated in the mineral crystalline structure or may be physically or chemically adsorbed or coprecipitated with clay minerals, organic substances, iron/manganese oxide/hydroxide coatings, or carbonates.

The presence of metals in the dissolved or extractable phase depends upon the chemistry of the metal and ambient physical and chemical conditions. Alkali and alkaline-earth metals (e.g. Ba, Sr) exist largely in the dissolved form. Dissolved to particulate ratios of 2:1 and 1:1 were found for B, Zn and Cd. Copper, Hg, Cr and Pb exist largely (55%-84%) in the particulate phase. Iron, Al and generally Mn are almost entirely (98%) transported in association with solids. Metals in the dissolved phase shift in equilibria toward the solid phase; this tends to occur along the course of a river under the regular flow conditions of each river. The exchange of metals from the solid-associated to the solute phase may be caused by a change in pH, salinity, redox conditions and by microbial activity (Forstner, 1977).

Changes in the total concentrations and proportions of dissolved and extractable metals occur over the seasons reflecting changes in source, the discharge and sediment regimes and biological uptake. Metals introduced from point sources are diluted during high flow conditions; those contributed from natural and anthropogenic diffuse sources may be increased or diluted as metals are mobilized from the drainage basin in solution and in association with mineral and organic solids. One would expect dissolved concentrations to be at their greatest proportion of the total metal concentration and of the total metal content over the year during periods of low flow and therefore low suspended sediment content. Metals essential for biological activity, e.g. Cu, Mn, Mo, may decline in the dissolved phase as the available fraction is bioassimilated during the period of productivity. Ecological impact of metals in either phase is dependent upon the physiochemical conditions controlling their availability. Fluvial sediment-related metals may only become available following release to the solute phase under various water conditions, caused by changing seasons and river locations or deposition in lakes.

Speciation of metals in the Mackenzie River basin is not evaluated here due to problems with the dissolved metal data (discussed in detail in Chapter 2), the presence of many of the dissolved metal concentrations below the detection limit, data gaps and inconsistency of analysis of both the dissolved and extractable fractions, analytical method changes and associated errors.

3.4.4 Seasonal Variations

Investigation of seasonal variations in metal concentrations is limited by data availability and is biased by the amount of data per month and irregular distribution over the year. Recognizing these limitations, seasonality of a few elements has been evaluated at Athabasca River at Athabasca. Figure 3.42 indicates monthly minimum, mean and maximum concentrations of extractable metals for the period of record.

Extractable Al, Cu, Fe, Mn and Zn mean concentrations peak from May to August. The peak coincides with the period of maximum discharge (Fig. 3.8) and of maximum suspended sediment content (measured as turbidity, Fig. 3.6). The latter is to be expected as Al, Fe and Mn in particular are strongly associated with solid material (see section 3.4.3). Extractable Sr declines from February to July, then increases in the fall. As Sr exists predominantly in the dissolved phase, concentrations are diluted during the high water period.

The monthly range of values for Al, Cu, Fe, Mn and Zn is several times larger in the open water period than under ice cover. This is due to the dependence of the metal concentrations on the suspended sediment concentration and the great variability of the latter. Variability is reduced from September to March when flows and sediment concentrations remain relatively constant. The monthly range of Sr values changes little over the year.

3.4.5 Spatial Variations

Metal concentrations at various sites were compared to investigate spatial variation within each subbasin. The number of sites for comparison was limited by the number of analyses at each site as well as by different groups of elements analyzed at different sites in the same subbasin. The amount of comparable data was further reduced, as data for different sites were frequently collected over different periods of time. Only same year data were compared to eliminate possible long-term concentration changes. Data obtained by different analytical techniques were not compared. It is important to note that data for different seasons were not paired, i.e., seasonal biases may exist in the site comparisons.

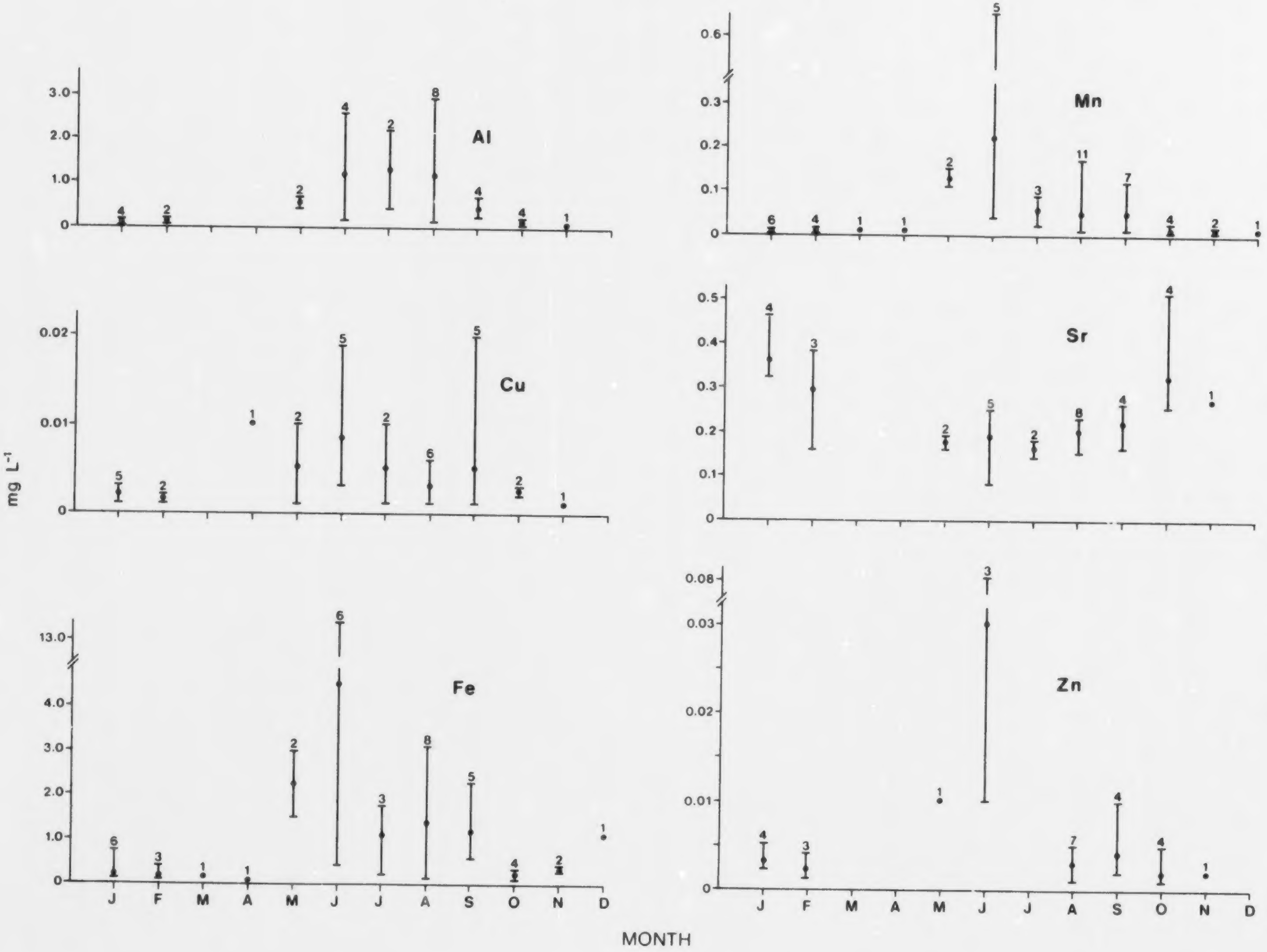


Figure 3.42 Seasonal variation (minimum, mean and maximum values) of extractable metals. Numbers refer to sample size. Athabasca River at Athabasca.

In a natural river system, increases in the concentration of extractable metals can be expected in the downstream direction as increasing amounts of suspended solids are introduced to the system. Metals in the extractable form may be from natural (weathering of igneous, sedimentary and metamorphic bedrock and organic and calcareous deposits) or anthropogenic sources. An extractable metal concentration increase in water may merely reflect a change in geology or an increase in mineral content and does not, therefore, necessarily suggest an anthropogenic input. Dissolved metals can be expected to decline downstream due to dilution or to remain at a constant level. A downstream increase in dissolved metal content therefore suggests a change in geology or in weathering rate or an anthropogenic source of the metal.

Results of the comparison of mean metal concentrations for a similar period of record between chosen sites are in Table 3.8. Downstream changes in concentration, identified by consideration of the mean as well as the range at each site, are indicated.

Concentration increases occur in the Athabasca River upstream from Sunwapta River to Athabasca for extractable Ba, Cu, Fe, Mn and Zn. Although the Athabasca site is downstream from oil and gas fields, livestock and farming operations and coal and copper mines, all of which are potential sources of metals, the concentration increases likely reflect the changing geology along the course of the river.

An increase in the extractable Pb concentration occurs in the Liard River subbasin upstream from Dease River to Fort Simpson. A large producing mine in the Dease River watershed or natural variation in geology may be responsible for the slight increase.

Extractable Fe, Mn, Cu, Al, Li, Ni and Sr show concentration increases in the Mackenzie River from Fort Providence to upstream from the confluence of the Arctic Red River. There is an eightfold increase in turbidity between the two sites, reflecting inputs largely from the Liard and other tributaries in the Western Cordillera. Although several oil and gas fields occur along this reach of the Mackenzie River, the

Table 3.8 Downstream Changes in Extractable Metal Concentrations (mg L^{-1}) in Mackenzie River Subbasins

Athabasca River Subbasin

Metal	Period of record	Athabasca River upstream from Sunwapta River Mean (range)*	Athabasca River at Athabasca Mean (range)*	Conc. increase
Fe	1972-75	0.60 (<0.04-2.10)	2.03 (0.08-13.4)	✓
Cr	1972-76	<0.015 (<0.015)	<0.015 (<0.015)	
Mn	1972-76	0.02 (<0.01-0.07)	0.09 (<0.01-0.09)	✓
Cu	1972-76	0.001 (<0.001-0.010)	0.004 (<0.001-0.019)	✓
Zn	1972-75	0.003 (<0.001-0.006)	0.010 (<0.001-0.08)	✓
Ag	1972-75	<0.01 (<0.01)	<0.01 (<0.01)	
Cd	1972-75	0.001 (<0.001-0.002)	0.001 (<0.001-0.002)	
Ba	1972-75	<0.10 (<0.10)	0.12 (<0.1-0.4)	✓
Pb	1972-75	<0.001 (<0.001-0.004)	<0.001 (<0.001-0.014)	

Liard River Subbasin

Metal	Period of record	Liard River upstream from Dease River Mean (range)*	Liard River near Fort Simpson Mean (range)*	Conc. increase
Pb	1973	<0.001 (<0.001)	0.003 (<0.001-0.008)	✓

Mackenzie River Subbasin

Metal	Period of record	Mackenzie River at Fort Providence Mean (range)*	Mackenzie River upstream from Arctic Red River Mean (range)*	Conc. increase
Pb	1972-79	<0.004 (<0.001-0.006)	<0.004 (<0.004-0.016)	
Fe	1960,72-79	0.26 (<0.05-1.00)	3.2 (0.10-12.5)	✓
Al	1975-77	0.15 (<0.10-0.30)	1.0 (<0.10-5.5)	✓
V	1972-74	<0.05 (<0.05-0.06)	<0.05 (<0.05-0.15)	
Cr	1972-78	<0.010 (<0.010)	<0.010 (<0.010-0.040)	
Mn	1972-79	0.01 (<0.01-0.07)	0.10 (<0.01-0.66)	✓
Co	1972-79	0.002 (<0.001-0.009)	0.003 (<0.001-0.015)	
Li	1972-74	0.006 (<0.005-0.016)	0.008 (<0.005-0.037)	✓
Ni	1972-77	0.003 (<0.001-0.010)	0.009 (<0.001-0.033)	✓
Cu	1972-79	0.002 (<0.001-0.007)	0.006 (<0.001-0.026)	✓
Zn	1972-79	0.013 (<0.001-0.075)	0.017 (0.001-0.047)	
Sr	1972-74	0.19 (0.07-0.26)	0.21 (0.15-0.35)	✓
Mo	1972-77	<0.05 (<0.05-0.23)	<0.05 (<0.05)	
Cd	1972-79	0.001 (<0.001-0.039)	0.001 (<0.001-0.003)	
Ba	1975-79	<0.10 (<0.10)	<0.10 (<0.10-0.35)	

* Numbers are mean concentrations of the elements covering the similar period of record.

increases in metal concentration probably are attributed to the increase in metal content associated with a greater amount of suspended material.

3.4.6 Time Trends

Changes in metal concentrations over time were investigated at selected sites with the longest periods of record. Annual mean concentrations, for metals with values above the detection limit, at the Athabasca River at Athabasca, the Smoky River at Watino and Mackenzie River at Norman Wells are given in Table E-3 of Appendix E.

Examination of the annual data over the period of record reveals that lower concentration means and a narrower range of values characterize 1960s data compared with data analyzed in the 1970s by a different analytical method (Fig. 3.43). Annual values may be biased seasonally by varying sample size, may reflect field and laboratory inaccuracies and suffer from the uncertain representativeness associated with one-time sampling (discussed in Chapter 2).

Slight increases over time in the mean concentrations of extractable Mn and Fe at Athabasca and of extractable Mn and Zn in Smoky River are suggested in Figure 3.43. The increases appear to begin in 1971 in the Athabasca River and in 1972 in the Smoky River, years which coincide roughly with the change in analytical methodology. It is not known whether the observed concentration increases are due to the change in methodology or reflect mining, oil and gas development in the Athabasca and Smoky watersheds.

3.4.7 Conclusions

Several conclusions can be drawn from interpretation of the metal data. Metal concentrations in the rivers and lakes of the Mackenzie Basin are at natural levels and are largely in association with suspended solids. The Athabasca and Great Slave lakes play an important role in the Mackenzie drainage network in reducing the metal load to the Mackenzie River by serving as settling basins for the suspended sediment content of the Athabasca, Peace and Slave rivers. Together with

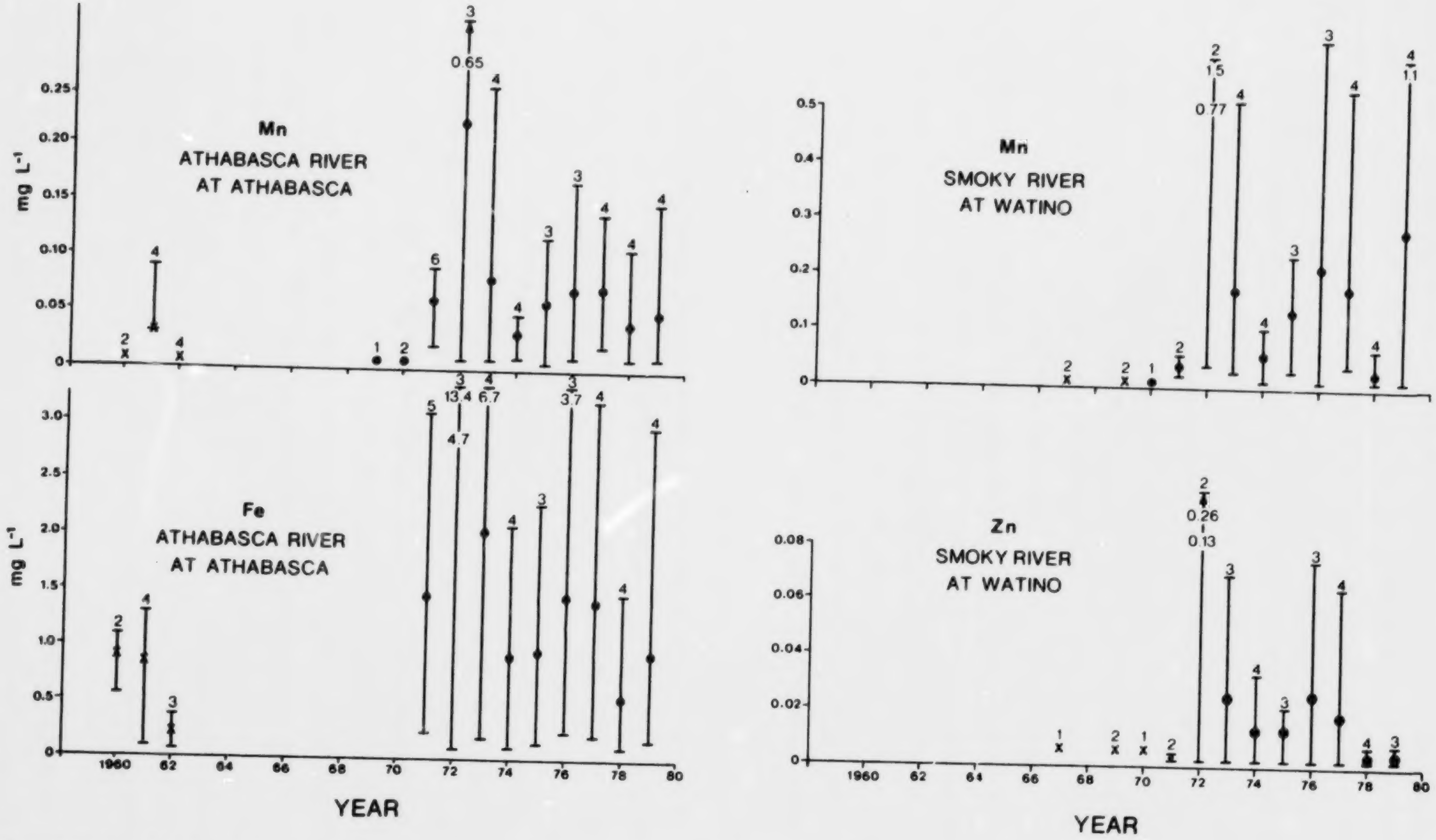


Figure 3.43 Annual minimum, mean and maximum concentrations of extractable metals at selected sites. X indicates early analytical method; solid circle represents recent analytical method; numbers indicate sample size.

Great Bear Lake, these lakes provide clear, relatively metal-free water to the mainstem Mackenzie River.

Metal concentrations in rivers vary seasonally in response to the discharge and sediment regimes and spatially reflecting natural variation along the course of the river. The variability of metal values is low over the winter and is markedly greater in the open water period.

Major anthropogenic influences in the basin are not directly evident in the metal data. Metal inputs from development, however, may contribute to the observed concentration increases downstream and over time for a few metals at selected sites. The potential for increased hydrocarbon, mineral and hydroelectric development in the basin is great. A complete, continuous metal data set is required to document background (natural) metal levels in water so that anthropogenic effects may be clearly identified. Only with this information will we be able to control inputs to maintain the basin waters in an ecologically healthy state.

A major problem in the interpretation of metal data lies in the uncertainty of the bioavailability of the various metal species. The dissolved fraction provides an estimate of the free ion concentration; for copper and likely for other metals this is an available fraction. The extractable analysis includes the dissolved fraction as well as solid-associated metals which may potentially be released to solution. Extractable values therefore provide an overestimate of the amount of potentially bioavailable metal. Until an analytical technique, sampling phase and/or specific monitoring strategy is established to characterize the available metal fraction, the impact of occurring metal levels upon the aquatic ecosystem cannot be determined.

3.5 Organic Parameters

3.5.1 Introduction

Organic parameters include phenolic substances, a host of chemical compounds used as insecticides, herbicides, and polychlorinated biphenyls (PCBs) and other industrial by-products. In the Mackenzie database, phenols, pesticides and PCBs are addressed. The substances are of anthropogenic origin, while phenols can also have a natural origin. They vary widely in chemical characteristics and their persistence in the environment. Many are capable of causing detrimental effects in the aquatic ecosystem due to their toxicities, the bioaccumulation in the food chain and the potentially carcinogenic nature of many of the compounds.

Trace amounts of phenols occur naturally in the aquatic environment as they are released by aquatic plants and decaying vegetation. Major anthropogenic sources of phenols include coal and wood distilleries, oil refineries, chemical plants, the degradation of phenolic pesticides, and animal and human wastes. The phenolic compounds impart an undesirable taste and odour, even at low concentrations, that limit use of the water. Phenols may affect freshwater fish by direct toxicity to fish and to fish food organisms. Gill damage, tissue lesions and decreased egg development occur in various freshwater organisms. The toxicity of phenol is enhanced by low dissolved oxygen concentrations, high salinity and water temperatures. As many phenolic compounds are resistant to biological degradation, they may be transported long distances in water and thus have far-reaching effects on the environment.

Pesticides are formulated to kill organisms perceived as undesirable. Although they are an economic necessity in agricultural regions, the effects of pesticides are undesirable if they extend beyond the area of use or persist longer than is required to complete their intended function. Pesticides reach the aquatic environment by way of aerial spraying, surface runoff and percolation from treated areas, sewage discharge and industrial effluents, and atmospheric transport. Polychlorinated biphenyls are a group of industrial chemicals distributed in North America under the brand name Arochlor. Industrial and municipal discharges are commonly the sources of most PCBs. The compounds are transported in water in association with solids and in the atmosphere.

Many of the pesticides and PCBs are highly resistant to biological, chemical and thermal degradation. They present an ecological concern because of their persistence in the environment and their ready incorporation and magnification in the food web. Adverse effects in organisms include degenerative changes in gills and visceral tissue, a decrease in growth and reproductive rate in fish, liver enlargement, tumours on various organs and a decrease in survival rate in organisms higher in the food chain. Some pesticides and PCBs ingested by humans in water and/or food are potentially carcinogenic. A few of the organic compounds are not bioaccumulated and degrade rapidly in the environment.

Interpretation of organic parameter data is very limited because of the lack of analytical results for many parameters at many sites, as well as the fact that most of the existing data are below detectable concentrations.

It is important to note that the inability to detect concentrations of the organic parameters in water with conventional methods does not indicate that the substance is absent from the aquatic environment. Many of the organic compounds are transported long distances in association with solid material, are ultimately deposited and undergo biochemical transformation processes. The medium in which the substance may exist (water, particulate [mineral or organic] or biota) varies with the season and stage of transformation. Lack of detection of the parameter in the water phase, therefore, may mean it is present in minute quantities below the detection limit or is in another phase. Even minute amounts of the compounds in water may accumulate in sediment and biota to potentially toxic concentrations.

3.5.2 Organic Parameter Values

Data for organic parameters in the Mackenzie River basin were collected in the Athabasca and Peace River subbasins. Only a few of the sites within the subbasins have data for the entire suite of organic parameters usually measured in water quality monitoring programs. The majority of the sites with organic data have been sampled merely because of site accessibility; many of the parameters have a limited number (less than ten) of observations. Most of the data on organic parameters have been collected in the 1970s.

3.5.2.1 Subbasins

Minimum, maximum and median concentrations of phenols, pesticides and PCBs in the Athabasca River (rivers and lakes) and Peace River (rivers) subbasins are given in Table E-4 of Appendix E. As most of the values are less than the detection limit, the median was chosen over the mean as a more representative subbasin value. Parameters for which the minimum, median or maximum value were detectable are shown in Table 3.9.

Rivers in the Athabasca River subbasin have the largest number of parameters with detectable values. This may reflect the greater number of observations for the subbasin, use of a variety of pesticides and PCBs in the agricultural and industrial regions, and atmospheric deposition. Values for lakes in the subbasin are one to three orders of magnitude higher than those for the rivers. The Peace River subbasin rivers have a few detectable parameters, with values in the same range as river values in the Athabasca subbasin. In a study of pesticides in Western Canada (Gummer, 1979), similar medians and ranges were observed for γ-BHC, α-BHC and 2,4-D in the Athabasca and Peace subbasins.

3.5.2.2 Selected Sites

Selected sites with organic parameter data are Athabasca River at Athabasca, Athabasca River upstream from Sunwapta, Peace River at Hwy. 29 and Smoky River at Watino. Parameters with values above detection levels at the sites are α- and γ-BHC (lindane) and 2,4-D. Table 3.10 lists the number of values above the detection limit, the high and low values reported and the months in which these values occurred at each site.

Of particular interest in Table 3.10 is the occurrence of high values of the compounds in spring (May) and/or late summer or fall (August, October). Low values of the compounds occur over the winter period (January, February). These occurrences are attributed to the time of use of pesticides and the chemistry of the compounds. Pesticide application over the summer months and the slight solubility of the

Table 3.9 Minimum, Median and Maximum Concentrations (μg L^{-1}) in Water of Detectable Organic Parameters in Mackenzie River Subbasins

Subbasin	Parameter	Athabasca			Peace		
		Minimum	Median	Maximum	Minimum	Median	Maximum
Rivers	Phenols (mg L^{-1})	<0.001	0.002	0.130	<0.001	0.002	0.034
	γ-BHC	<0.0007	<0.0007	0.0013	<0.0007	<0.0008	0.001
	α-BHC	<0.001	0.003	0.010	<0.001	0.004	0.008
	Arochlor 1254	<0.002	<0.03*	0.019			
	Arochlor 1248	<0.002	<0.02*	0.165			
	Arochlor 1260	<0.005	<0.055*	0.007			
	Ethion	<0.01	<0.01	0.01			
	2,4-D	<0.004	<0.004	0.05			
	2,4,5-T	<0.002	<0.002	0.009	<0.002	<0.002	0.009
	Dichlorprop	<0.004	<0.004	0.010			
Lakes	Phenols (mg L^{-1})	<0.002	0.03	0.08			
	Arochlor 1248	<0.055	<0.777*	1.70			
	Arochlor 1260	1.90	2.00	2.40			

*A change in analytical detection limits took place during the period of record of the parameter.

Table 3.10 Observations of Organic Parameter Data at Selected Sites

Site	Parameter	Observations	Low values	High values	Detection limit
Athabasca River at Athabasca	α-BHC	n = 8 >d.l. = 7	Jan. <0.001	Aug. 0.010 Oct. 0.009	<0.001
	2,4-D	n = 16 >d.l. = 2	Jan. Feb. <0.004 May, June Aug.-Oct.	May 0.017 Aug. 0.009	<0.004
Athabasca River upstream from Sunwapta	α-BHC	n = 1 >d.l. = 1		Aug. 0.002	0.001
	2,4-D	n = 1 >d.l. = 0			
Peace River at Hwy. 29	γ-BHC	n = 1 >d.l. = 0			
Smoky River at Watino	γ-BHC	n = 19 >d.l. = 1		Aug. 0.001	<0.001
	α-BHC	n = 15 >d.l. = 9	Jan. Feb. <0.001	May 0.006 Aug. 0.007 Aug. 0.008	<0.001

n = Number of observations.
>d.l. = Number of data observations above the analytical detection limit.

NOTE: Concentrations are in micrograms per litre.

compounds in water as well as their ability to sorb to organic matter likely explain the summer and fall high values. The compounds are readily adsorbed to mineral material, thus explaining the highs observed in the spring (May) when suspended sediment concentrations are elevated and pesticide residues are flushed from the watershed during snowmelt and by surface runoff. Accumulation of pesticides deposited over the winter from atmospheric sources likely contributes to the load during snowmelt. The low values are observed in winter when pesticide contribution from land surfaces is low or nil, and mineral and organic transport in the rivers is minimal.

3.5.3 Conclusions

There is a paucity of data on organic parameters in river and lake systems of the Mackenzie River basin. Organic parameter data for the Mackenzie River basin indicate that detectable levels of some contaminants in water may be found in the open water period and levels are below detection limits under ice cover in the Athabasca and Peace River subbasins. Levels in water cannot be used to describe contaminant impact upon the aquatic system owing to the scarcity of data and the uncertainty of concentration and effect relationships in the ecosystem. Compounding factors include the limitations in analytical detection limits and the seasonal changes in concentrations of organic compounds in water, sediments and biota. No organic data exist for the Liard, Hay, Great Bear, Great Slave and Mackenzie subbasins.

In view of the wealth of natural resources in the basin, present and future developments create the possibility of potential increases in anthropogenic inputs of organic substances. The sensitivity of the northern ecosystem and the detrimental biological effects of organic contaminants in the aquatic environment highlight the necessity for expanding the monitoring for organics in the Mackenzie River basin and acquiring a scientifically sound organic parameter database.

Water Quality Guidelines for the Protection of Aquatic Life

To assess the suitability of a body of water for a given use, a common method is to compare the measured concentrations with pre-established guidelines or water quality objectives. Among the most common uses of surface water, i.e., supply for drinking water, irrigation, watering of livestock, recreation and support of aquatic life, usually the last use is the most sensitive to water quality. To give the reader an idea of the suitability of water for aquatic life, the quality of the waters of the Mackenzie River basin is compared with water quality guidelines for aquatic life.

To date, no guidelines have been developed specifically for northern environments. Guidelines that can be found in the scientific literature have been established based on studies carried out in warm or temperate environments. One would expect that they would be different in northern waters. Although this section compares the water quality in the Mackenzie River basin with guidelines established elsewhere, it must be emphasized that to reach a good understanding of the capability of rivers and lakes of the Mackenzie River basin to support different uses, guidelines and objectives specific to these waters must be established.

Appendix F shows existing guidelines for aquatic life. Values of TDS in rivers and lakes of the subbasins are approximately one half to one third of the proposed guideline. Values of pH rarely exceed the suggested range.

A guideline exists for un-ionized NH_3; data, however, exist only for NH_4^+ and only in the Athabasca and Peace subbasins. In the pH range of the river waters, it is probable that the nontoxic NH_4^+ predominates over un-ionized NH_3. It is therefore unlikely that ambient concentrations of NH_3 exceed the guideline. Concentrations of NH_3 that exhibit toxic effects to aquatic life are not known to or are unlikely to occur; concentrations of the species in Mackenzie waters are several orders of magnitude below these levels.

Total phosphorus concentrations of 0.10 mg L^{-1} in flowing water, 0.05 mg L^{-1} for water flowing into lakes and reservoirs and 0.025 mg L^{-1} in lakes and reservoirs are the recommended guidelines to limit the eutrophication of freshwaters. The concentrations of TP in Athabasca, Great Bear and Great Slave lakes (0.022, 0.028, 0.021 mg L^{-1}, respectively) approach or slightly exceed the guidelines set for lakes. These water systems, however, are not eutrophic, as the availability of phosphorus, as well as other factors (e.g., turbidity, morphometry, flows, nitrogen availability), is involved in mediating vegetative growth. Lake Erie, in comparison, is a very eutrophic system and yet has a lower phosphorus concentration than lakes in the Mackenzie Basin. The comparison emphasizes the inapplicability of the guidelines to a northern environment. It is also important to note that the current phosphorus guidelines refer to the total phosphorus and not specifically to the bioavailable fraction. As illustrated in an earlier section (3.3.2), only a portion of TP occurs as the available species. Thus it may be misleading to be alerted by exceedances at a time when they increase in rivers with increases in discharge, while the available species are decreased by dilution. In the case of lakes in the Mackenzie Basin, the phosphorus is almost entirely in an unavailable mineral form and thus does not contribute to eutrophication in the short term.

Even though metals and organic compounds appear to be in compliance with guidelines in the Mackenzie Basin, this does not imply that the compounds are present in concentrations that are non-damaging to the Mackenzie ecosystem. The apparent "non-compliance" observed for lead in Great Bear Lake and phenolics and PCBs in rivers of the Athabasca and Peace subbasins must be interpreted with particular care and, most important, investigated in more detail. It must also be pointed out that the guidelines refer to the total values and thus do not refer to the amount of active species in the dissolved state or the concentration of potentially available compound in the particulate-associated form. Furthermore, studies have shown that biota acclimate to a certain extent to the conditions which exist in a particular water body and therefore concentrations which might appear to be toxic are not so in that water body.

Although it is not possible to evaluate with any degree of certainty the status of the water quality in the Mackenzie River basin, indications are that the basin is largely in a natural, undisturbed state. As resource development and the accompanying industries and support services expand, it will be essential to have a set of water quality guidelines tailored to northern ecosystems so that the quality of the water may be protected for the preservation of aquatic life and ultimately for the local inhabitants.

Conclusions and Recommendations

The material in this report has been derived from data collected from conventional water quality networks and studies established in the 1950s. Site locations, parameters sampled and frequency of sampling reflect the water quality concerns and objectives of that time period. However, national water quality issues have substantially changed from the 1950s to include eutrophication, metal contamination, toxic substances and long-range transport of pollutants. As a result, the sampling strategy for the Mackenzie Basin must reflect current monitoring objectives and water quality issues of the 1980s.

Physical parameters and major ions are traditionally sampled parameters. A considerable amount of data exist for the Mackenzie Basin, covering the entire period of record (1960-1979) and generally collected on a monthly basis. Large data sets exist for many stations and in all subbasins. The data are sufficiently complete to permit interpretation of source, spatial and seasonal trends, interparameter relationships and time trends. The data provide information capable of reflecting the behavior and natural or anthropogenic changes in levels of the measured parameters. Sampling coverage for the Shield region is relatively sparse compared with elsewhere in the basin.

1 It is recommended that the frequency of sampling of major ions be reduced. From the data set, ion variability appears to be well documented and changes minimally over time.

The period of record for nutrients is shorter and less continuous than that for physical parameters and major ions. Although TKN, TP and TOC are sampled periodically at many sites, only NO_2^- - NO_3^- is sampled at a wide range of sites on a regular (quarterly) basis. Data on speciation of N, P and C are very limited at some sites and are not available at all at many sites. Data for the species that are measured do not span all months or even all seasons.

The low sampling frequency does not permit resolution of nutrient variability in the short term or definition of long-term trends. A different number of sample analyses per species, collected at different times of the year, does not permit observations on downstream or temporal trends or on biochemical transformations of the nutrients. The discontinuity of data over time and the different analytical techniques used over time and by different laboratories severely limit the evaluation of time trends.

2 It is recommended that sampling frequency for nutrient parameters be increased. Quarterly sampling does not adequately characterize nutrient variability. Recurrent surveys, in conjunction with or in place of fixed station monitoring, would be an effective strategy for characterizing variability of these nonconservative parameters.

3 It is recommended that relationships be established between different analytical techniques so that meaningful comparisons can be made of data analyzed by different methods over time.

4 It is recommended that sites within each subbasin be monitored with the objective of providing spatial, seasonal and long-term information on nutrients. This could be achieved by complementing a fixed station network with surveys.

Data for metals exist in all subbasins and generally cover the early 1960s and later 1970s. Data are plentiful for extractable metal levels in the Athabasca, Peace and Mackenzie subbasins but are relatively sparse in the remaining subbasins. The period of record of the individual metals varies considerably at each site. Dissolved metal concentrations were rarely measured; where data do exist, they rarely complement the extractable metal levels. Extractable and dissolved concentrations are difficult to interpret not only because they are generally close to or below the detection limits in water but also because they are merely chemical measures rather than actual environmental entities. Due to the difficulty in detecting values and the uncertainty of values around the detection limit, investigation of spatial, seasonal and time trends is tenuous if at all possible.

5 It is recommended that a medium that concentrates metals be monitored, as well as, or in place of, water. Metal analysis of an affected medium (e.g. biota) would provide a direct measure of the bioavailable metal fraction. As this is the fraction capable of exerting far-reaching and negative effects upon the ecosystem, it is imperative to quantify its presence. Focus on a medium (e.g. sediments, biota) containing higher concentrations than in water would permit a greater degree of confidence in the detected values and enable investigation of trends. Multi-media sampling is readily carried out by way of surveys.

6 Whatever the sampled medium, similar analytical techniques must be used in each subbasin and preferably throughout the basin to permit site and subbasin comparisons. Consistent use of an appropriate technique over time would facilitate time trend analysis.

7 In view of the variety of development activities in the Mackenzie Basin and the potential for their expansion, it is recommended that coverage of metal analyses be increased, particularly in the Liard subbasin.

Organic parameter data exist only in the Athabasca and Peace subbasins and only at a limited number of sites. Most of the results are below the conventional detection limits.

8 It is recommended that a medium containing potentially higher concentrations of the organics be sampled to enable characterization of low levels of contamination in the aquatic system. Sediments and biota, known to concentrate these parameters, may be more suitable media.

9 Analysis of biota may serve as an environmental warning of low levels of contaminants in the system, as well as an indication of the bioavailable component. As in the case of metals, surveys are an effective way of studying the multi-media presence of contaminants.

10 Coverage of organic parameters should be increased with the monitoring focus on areas presently or likely to be subjected to organic loadings. These areas include the Slave River and the reaches upstream and downstream from Norman Wells.

Difficulties involved in the comparison of the northern water quality data with guidelines designed for temperate aquatic systems were recognized. Until the research base on northern environments has been augmented such that objectives specific for the North can be established, we will have to accept the guidelines, difficulties notwithstanding. It is recommended that nitrogen and phosphorus, and metals and organics that are likely to become problematic, be given priority consideration for the development of objectives.

Implementation of these recommendations would improve the quality of data and the amount of information obtained from the basin. The recommendations should be considered when the monitoring program in the North is assessed and/or modified, and should only be implemented following detailed assessments of the existing data, physical factors, water use and existing and potential developments. The assessments would provide a rational basis for upgrading the monitoring network, implementing the recommendations, and designing surveys which would evaluate water quality issues of concern in each subbasin.

In summary, the present monitoring network and strategy generates data that provide useful information on physical and chemical characteristics of the water and very limited information on nutrients. Sparse data available for metals and organics provide no insight on processes and effects. A sampling design with different parameter and medium emphasis, different site locations and sampling frequencies and including survey studies as an active component of the monitoring strategy would generate the information base necessary to meet effectively the current scientific questions and management information requirements for the northern aquatic resources.

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Appendix A
Environmental Setting

Environmental Setting

A.1 Introduction

The water quality of a river basin is the product of a complex series of physical, socio-economic and cultural factors. The factors influencing the quality of Mackenzie River basin waters are described. Material in this section is largely from the Mackenzie Basin Intergovernmental Liaison Committee.

A.2 Physical Factors

Physical factors affecting water quality in the Mackenzie Basin include geology, physiography, climate, soils, vegetation, permafrost and hydrology.

A.2.1 Geology

The Mackenzie Basin comprises four geological provinces: the Western Cordillera, the Interior Plain, the Canadian Shield and the Arctic Coastal Plain (Fig. A-1).

The Western Cordillera is composed largely of folded sedimentary rock, primarily Paleozoic limestones and dolomites. Volcanic strata and massive metamorphic rocks, intruded with numerous bodies of igneous and volcanic rock, are also present in the region.

The Interior Plain is underlain by Proterozoic sedimentary rocks. Southern sections are composed of a relatively thick blanket of Mesozoic (Cretaceous) and Cenozoic (Tertiary) clastic rocks that overlie carbonate sediments and evaporites of the Paleozoic era and a basement of Precambrian sedimentary rock. In the northern section, Devonian and older clusters of carbonate sediments and evaporites lie on Precambrian sedimentary and crystalline rocks and are covered by a thin veneer of late Lower Cretaceous rocks. Cenozoic sandstones are along the banks of the Pembina and Great Bear rivers. Paleozoic sandstones exist in the British and Richardson mountains.

The Canadian Shield is composed of Precambrian igneous granites and gneisses with bands of volcanic and sedimentary rocks. In northern sections, these Precambrian rocks are overlain by volcanic rock and sediments of dolomites and shale. In the south, the Precambrian rocks are buried by a series of shales and limestones. The layers may have been metamorphosed, intruded by granite and then buried by sedimentary and volcanic rock.

The Arctic Coastal Plain extends from the Arctic Continental Shelf, approximately 160 km offshore, to beneath the Mackenzie Delta. The Arctic Coastal Plain consists of Cretaceous and Cenozoic rocks overlain by alluvium and glacial drift.

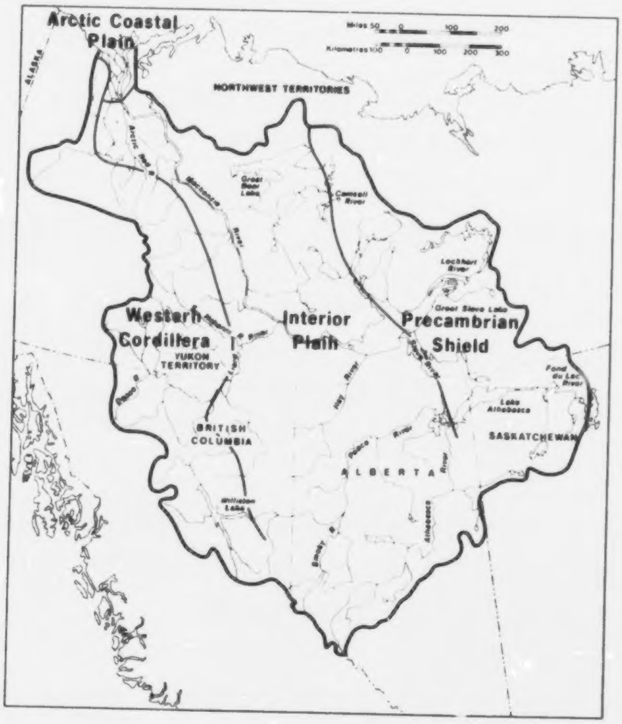


Figure A-1 Geological provinces of the Mackenzie River basin.

A.2.2 Physiography

As the physiography of the Mackenzie Basin is dominated by the geology, the Basin can be divided into physiographic regions corresponding with the geological provinces.

The Western Cordillera represents the divide between western and northern-flowing rivers in Western Canada. It consists of two mountain systems, each aligned in a northwest direction. The western system, which forms the western boundary of the Mackenzie Basin, includes the Rocky, Cassiar and Franklin mountains. These mountains are extremely rugged and rise to elevations of more than 3500 m. The eastern system includes the Omenica and Mackenzie mountains, which rise to elevations of 2500 m. Between the two systems lies a relatively flat area which includes the Liard Plain and Plateau and the Rocky Mountain Trench. Both mountain systems are broken into several segments by east-west belts of relatively low terrain, occupied by the major eastward flowing rivers (the Liard, Nahanni and Peel).

The Interior Plain is 300-600 km wide and extends the length of the basin. The relatively flat southern portion of the Plain, known as the Alberta Plateau, is interrupted by the Fort Nelson and Peace River lowlands which slope from an elevation of 800 m in the southwest to 300 m in the north. The northern section, containing Great Slave and Great Bear Lakes, is known as the Mackenzie Lowlands.

The Canadian Shield is a mosaic of lakes interspersed with ridges and hummocks of glacial till. The area is poorly drained. South of Lake Athabasca, the Shield is known as the Athabasca Plain, an area of nearly flat-lying, unmetamorphosed sandstones rising from an elevation of 300 m in the west to 600 m in the east. Drainage in the area is almost entirely into Lake Athabasca. North of the lake, the Shield includes portions of the Kazan and Bear-Slave uplands. These areas are massive rock batholiths, which range in elevation from 300 to 600 m and contain numerous lakes.

The Arctic Coastal Plain underlies the Mackenzie Delta. The plain includes the present delta as well as relicts of former deltas and fluvial and marine features. The delta area contains a multitude of lakes and channels. One of the outstanding features are the pingos, dome-shaped hills composed of ice and some surficial material. They rise up to 30 m above the surrounding terrain and are 10-100 m in diameter.

A.2.3 Climate

The Mackenzie Basin is characterized by long cold winters and brief cool summers. Uniform weather patterns prevail for extended periods of time due to domination by polar air masses. Up to 90% of the annual precipitation falls from May to September. Cyclonic activity is restricted to the spring and fall seasons. The basin encompasses the tundra and subarctic climatic regimes.

The subarctic regime dominates the basin, with the tundra regime limited to the northeastern part of the basin and the high altitudes of the Western Cordillera (Fig. A-2). Climatic variations within each regime are shown in Table A-1.

Table A-1 Selected Climatic Data for the Mackenzie Basin

Station	Climatic regime	Annual mean daily temp. (°C)	Annual mean rainfall (cm)	Annual mean snowfall (cm)
Inuvik	Tundra	-9.7	10.7	174.0
Tuktoyaktuk	Tundra	-10.7	7.3	55.6
Yellowknife	Subarctic	-5.5	13.9	119.4
Dawson Creek	Subarctic	1.2	25.3	167.1

During winter, the Mackenzie Basin receives little direct solar radiation because of the low angle of the sun's rays. Temperatures drop and a stable high pressure system develops. Temperatures can be -50°C during the night and reach daytime highs of only -40°C. Precipitation is minimal. In the southern portions of the basin, where the high pressure systems are not as stable, Pacific air may cross the Western Cordillera, bringing heavy snowfalls.

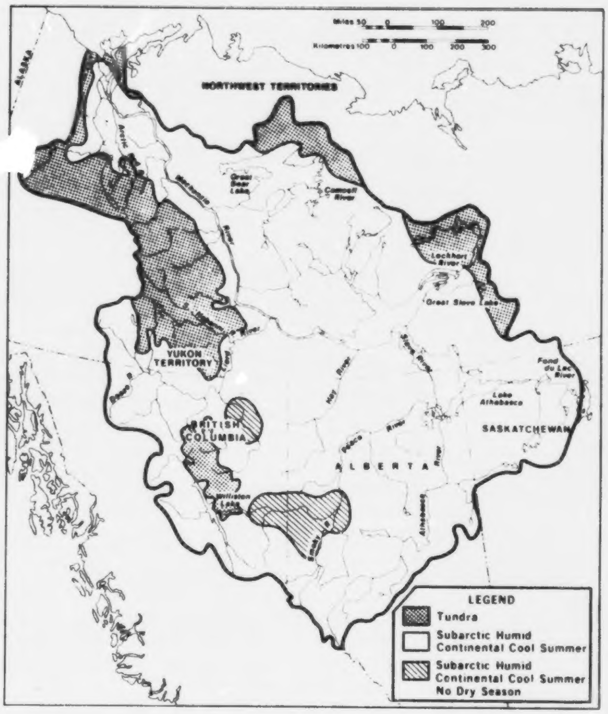


Figure A-2 Climatic regions of the Mackenzie River basin.

Temperatures increase in the spring, eroding the high pressure system northward. Storm frequency increases. By June most of the snow has melted, although lake ice may persist until the end of the month.

In the southern portion of the basin, the summer season is warm and convective showers and thunderstorms are common. Near the Arctic coast, most summer rains develop around weak lows travelling southeast from the Beaufort Sea or cloud masses drifting onshore from the Arctic Ocean. At this latitude, dramatic temperature changes can occur as wind shifts can bring warm air north from the Prairies or cold air south off the arctic ice pack.

The incidence of storms increases in the fall as cold air interacts with the remaining warm air masses. Temperatures continue to fall and the lakes begin to freeze. By late December or early January, the weather patterns become more stable and the clear cold winter regime sets in.

A.2.4 Soils

Soils in the basin reflect local and regional variations in climate, bedrock, relief, surface features and vegetation. Figure A-3 indicates the main soil regions of the basin; Table A-2 outlines the soil features. Soils in the southern part of the basin develop in a manner similar to mineral soils of a boreal forest.

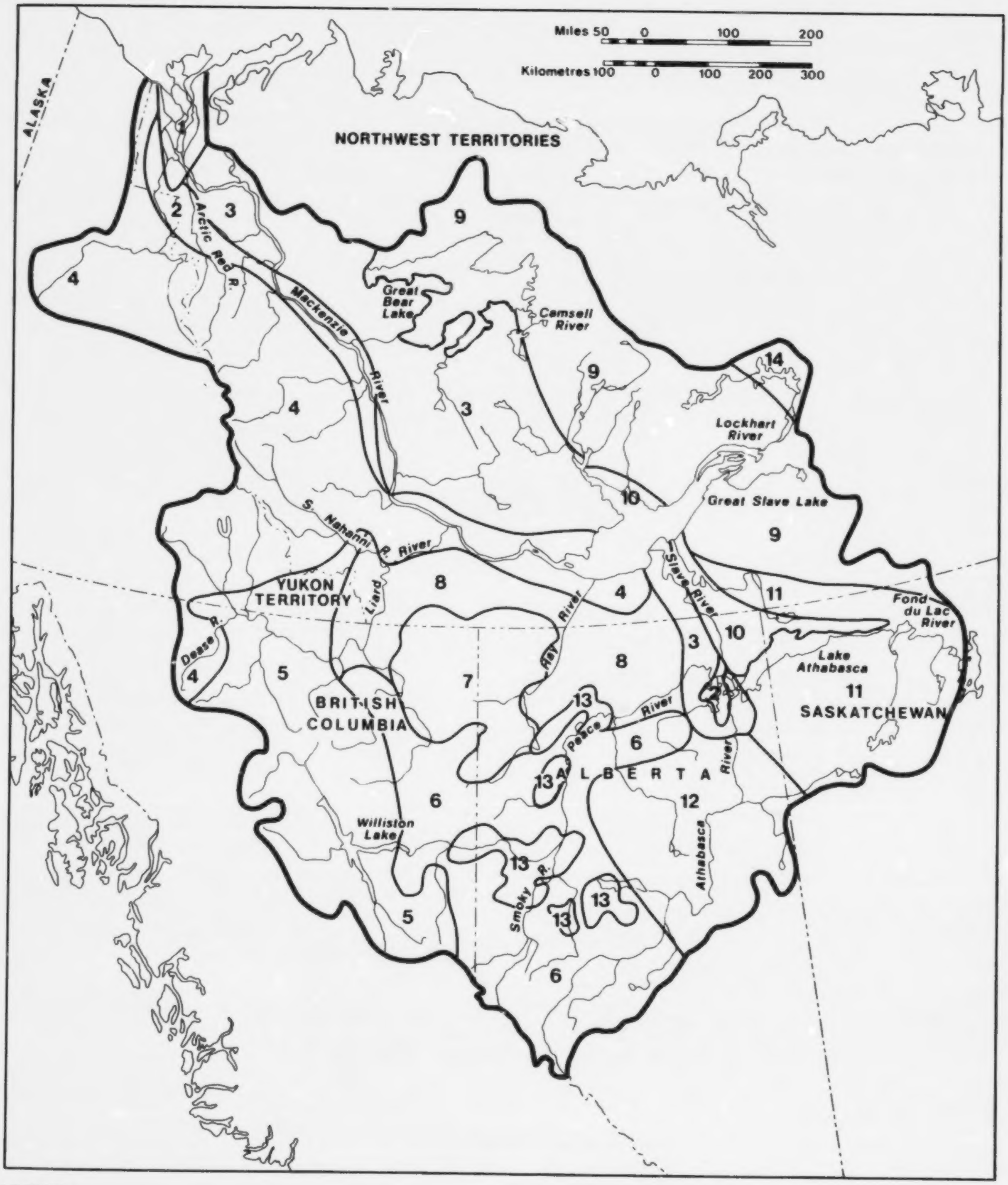
Soils in northern portions of the basin are influenced by low temperatures, either from ice contained within the profile or from the underlying permafrost. Organic soils (peat) are widespread. Soil profiles are poorly developed due to low biological and chemical activity, and physical disruption caused by frost churning. In permafrost areas, rooting depth limits soil development. In discontinuous permafrost zones, soils consist of sands and gravels. Upland soils are silts and clays with hummocky surfaces; the hummocks are due to freeze-thaw above the permafrost table.

Organic soils occur where poor drainage, high water table or seepage have resulted in the accumulation of peat. The soils generally develop in the depressions of former lakes and ponds, commmon in the Shield area and the northern portions of the basin. Peat is formed mainly from a mixture of sedges and mosses and cover about one eighth of the basin area.

A.2.5 Vegetation

Vegetation zones in the Mackenzie Basin include tundra, boreal forest, subalpine forest and aspen parkland (Figure A-4). Major factors affecting the zonation are permafrost and topography; climate, soil, relief and fire history are of secondary importance.

The arctic tundra is a generally flat, treeless plain lying in the extreme north and northeast corner of the Mackenzie Basin. Shrubs, lichens and mosses dominate the well-drained sites, while cottongrass-sedge meadows are common in the poorly drained areas.



LEGEND

1	Cryic Gleysolic (alluvium) - delta	8	Gleysolic (grey wooded soils)
2	Cumulic Regosol - alluvium river sediments - undifferentiated	9	Brunisolic (Dystric) - grey wooded soils with peat and rock
3	Organic (Cryic Fibrisol) sub-arctic soils with peat	10	Bedrock (dominant rock outcrops with shallow Gleysolic soils, sands and moss)
4	Brunisolic (Eutric) - mountain soils with sub-arctic soils	11	Humo-Ferric Podzol (podzols with peat, bare rock and grey wooded)
5	Luvisolic (mountain soils) - mineral soil	12	Fibrisol Organic (moss and peat bogs)
6	Grey Luvisolic (grey and brown wooded soils with peat) - mineral soil that is seasonally saturated and which has ice lenses	13	Solonetzic (grey wooded soils with dark grey Gleysolic soils and peat)
7	Organic (Cryic Fibrisol)	14	Cryic Regosol (tundra soils)

Figure A–3 Soil regions of the Mackenzie River basin. Source: Mackenzie River Basin Reference Binder.

Table A-2 Features of Soils in the Mackenzie River Basin

Group	Drainage	Parent material	Fertility	Horizons
Gleysol	Well and imperfectly drained.	Neutral to alkaline in reaction. Vegetation coniferous – deciduous or boreal forests.	Low	Impoverished, light grey, leached layer at or near surface. Organic layer is thin, leafy mat.
Grey Luvisol				Dark grey surface horizon, 7-22 cm. Light, grey platy structured subsurface.
Solonetz	Well and imperfectly drained.	Coniferous and mixed forests	Medium	Pronounced horizons, extensive leaching and good moisture content. Grey layer at or near the surface. Organic matter accumulated in subsurface horizon.
Brunisol (Dystric)	Good to imperfect drainage.	Mixed forest, heath, tundra and alpine. Neutral to mildly alkaline reaction.	Medium	Well-developed horizons.
Brunisol (Eutric)		Mild to moderately alkaline reaction. Alpine transition zone.		
Cryic Gleysol	Water-saturated.	Mixed forest, peat, heath, moss, tundra.	Low	Organic surface of less than 35 cm of peat and up to 53 cm of peat moss. Restricted horizon development due to excessive water and little aeration.
Organic (Cryic Fibrisol)				Dark coloured; more humus in subsurface.
Fibrisol (Organic)				Podzolization present.
Cryic Regosol (tundra soils)	Very poorly drained.	Bare rock, tundra. Strongly acid in reaction.	Low	Underlain by permafrost organic horizon fairly thick. Northern counterpart of Gleysols.
Bedrock				Rock outcrops with shallow Gleysol soils, sands and moss.
Organic (Cryic Fibrisol)	Good drainage.	Thin, shallow soils. Found on terraces and dune sands.	Low	Podzolization and other processes weakened due to severe climate. Brown due to mineral elements combining with organic residues. Limited leaching.

Source: Mackenzie River Basin Reference Binder.

Table A-2 Continued

Group	Drainage	Parent material	Fertility	Horizons
Humo-Ferric Podzol	Well to imperfectly drained.	Loess, recent glacial till. Good to moderate oxidizing conditions.	Low	Thin and grey; surface horizon may be developed. Subsurface material is deep, unconsolidated, soft mineral matter.
Cumulic Regosol	Good drainage.	Fluvial parent materials.	Good	Varied profile and depth according to the extent of active deposition.
Luvisol (mountain soils)	Great differentiation.	Alluvial, glacial and periglacial materials.		Shallow; high stone and gravel content. May exhibit characteristics of other predominant groups according to site, exposure and denudation.

The alpine tundra region extends from the 2500-m elevation to the barren rocky peaks in the Western Cordilleran region. The alpine tundra is dominated by low-lying, drought resistant plant species which are able to withstand deep snow cover.

The subalpine forest dominates the southern portion of the mountain ranges. The region supports coniferous forests of Engelmann spruce, white spruce and alpine fir, as well as stands of Douglas fir and pine. At the 2000-m elevation there is a gradual breaking up of the forest into tree "islands" and then finally into isolated dwarfed trees.

The boreal forest is a closed-canopy forest of tall trees with luxuriant shrub, herb or moss ground vegetation. In southern areas, deciduous and coniferous trees, primarily aspen, lodgepole pine and jack pine prevail. Wetter areas are dominated by black spruce and tamarack. Deciduous trees gradually decrease in density northward and are replaced by black spruce and other conifers.

Trees in the subarctic forest are stunted in growth and are widely spaced. The openess of the tree canopy permits the growth of lichens and low shrubs. The dominant vegetation is black spruce, with

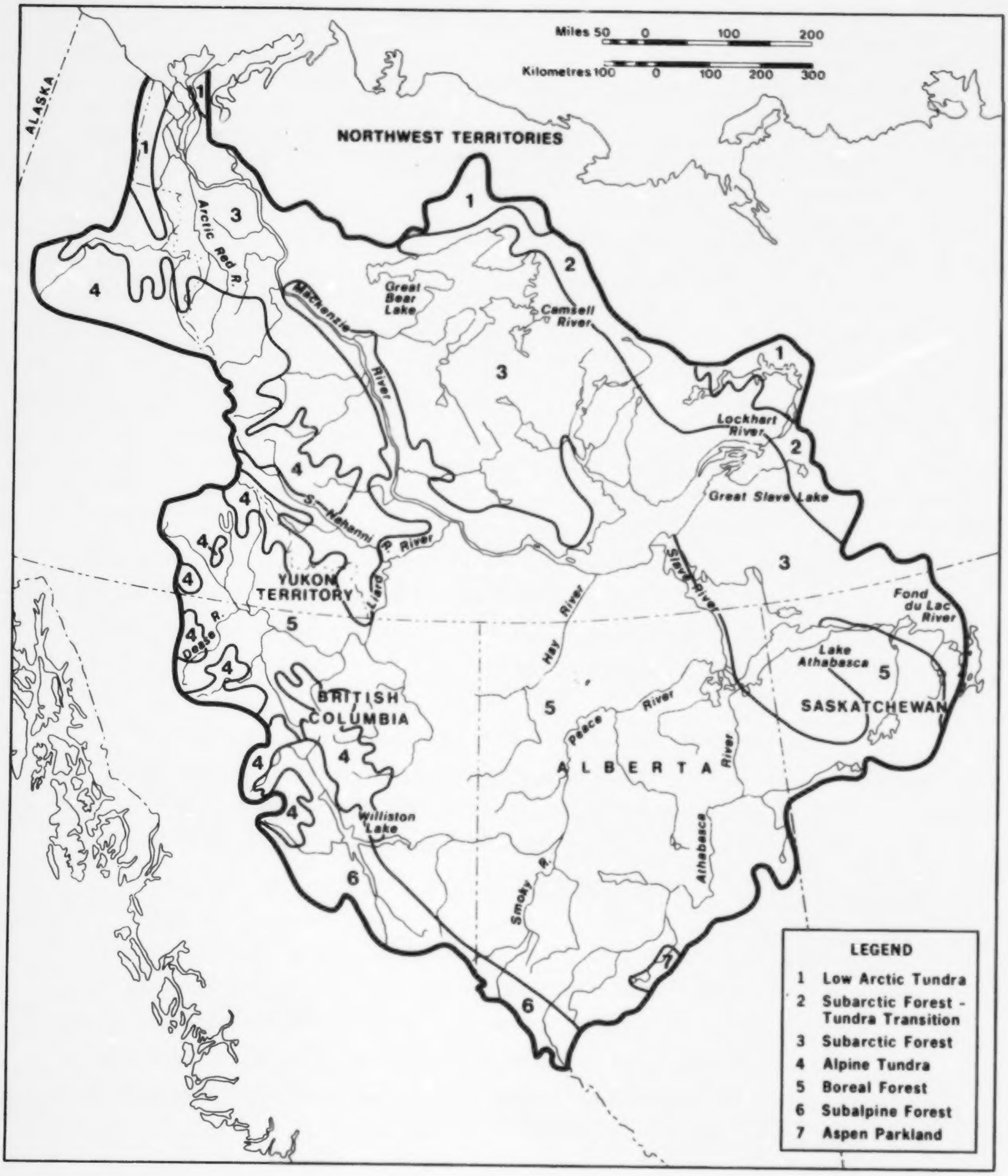


Figure A-4 Vegetation regions of the Mackenzie River basin.

elements of the boreal forest evident only in nutrient-rich alluvial soils.

The Peace-Athabasca Delta, the Peace River Lowlands and isolated areas in northeastern Alberta are covered by aspen parklands. Groves of aspen poplar are interspersed with prairie grasses, and valleys support dense stands of aspen, willow and conifers. Aspen parkland is found in areas recently destroyed by fire, as it is a primary stage of succession.

A.2.6 Permafrost

Permafrost involves the permanent freezing of soil or substrate. It forms where the mean annual temperature is below freezing and there is enough moisture in the ground to keep it frozen for extended periods. The layer of material overlying the permafrost, called the active layer, is frozen in winter and becomes an unstable surface when it

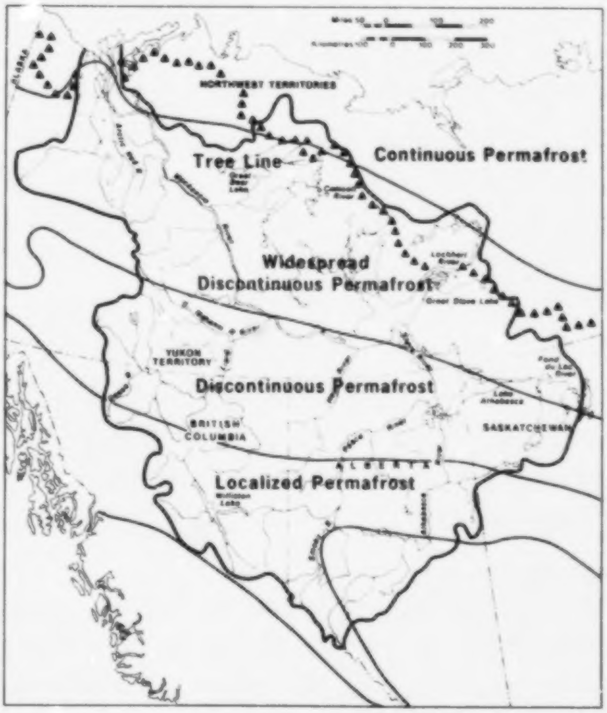


Figure A-5 Permafrost zones in the Mackenzie River basin.

thaws in summer. The presence of permafrost impedes water percolation and drainage thereby affecting the water quality.

The Mackenzie Basin has zones of localized, discontinuous and continuous permafrost (Fig. A-5). Localized permafrost occurs in the southern portion of the basin, is less than a few metres in depth and is very limited in extent. In the discontinuous zone, permafrost is generally confined to peatlands, north-facing slopes and forested river banks. Depths of the permafrost in this zone vary from 60 m in the north to a few centimetres in the south. Permafrost in the continuous zone occurs throughout the area except in newly deposited unconsolidated sediments; its depth ranges from 60 to 300 m. The depth of the active layer ranges from 0.5 to 1.0 m.

A.2.7 Hydrology

Runoff characteristics of the Mackenzie River subbasins are affected by precipitation, temperature, permafrost, groundwater, topography, vegetation, lake storage, soils and bedrock. Runoff influences the magnitude and behaviour of many water quality parameters.

Temperatures below freezing for six months of the year result in low runoff during the winter. Spring snowmelt produces high runoff as the frozen surface prevents significant infiltration. Sediment transport, almost negligible under ice cover, increases dramatically during breakup. Increases in sediment concentration in the water accelerate the breakup due to reduced albedo of the ice cover. Snowmelt proceeds northward in the basin with the advance of spring. River ice breakup, however, commences in the middle portion of the basin because of high spring inflow from the Liard River. Breakup farther downstream is delayed due to its more northerly location, while breakup at the headwaters is delayed by the stabilizing effect of Great Slave Lake.

The mountainous areas of the Cordillera receive relatively more precipitation than other regions of the basin. The steep slopes and impermeable terrain contribute to the higher rate of runoff than elsewhere in the basin, as well as to a high capacity to transport suspended sediments. Rivers in the Cordilleran region contribute a high proportion of the total flow to the Mackenzie system (Fig. A-6). Although the spring breakup is frequently the time of maximum discharge and suspended sediment transport, peaks may occur in mid to late summer during severe rainstorms. Small permanent glaciers also contribute to the flow over the summer period.

Drainage in the Interior Plain is characterized by a myriad of bogs and ponds connected by intermittent channels. Appreciable inflow of groundwater occurs only in areas that are not underlain by permafrost. Isolation of the surface waters for large parts of the year and the slow rate of flow across the plain have marked effects on the water quality.

Flows in the Shield region are low. Less rainfall, more uniform relief, minimal contribution of groundwater and impervious, erosion-resistant bedrock explain the low discharge and suspended sediment concentrations.

The Athabasca, Great Slave and Great Bear lakes play important roles in the hydrologic system of the basin. Lake storage is a main source of streamflow during winter months and directly contributes to groundwater recharge. By increasing the retention time of water in the drainage system, lakes even out flow and temperature variations, serve as settling ponds of suspended sediment and influence the timing and intensity of ice breakup.

A.3 Socio-Economic Factors

The socio-economic factors that affect water quality include mining, oil and gas, forestry, agriculture, rural expansion and hydroelectric development. Many of the resource development activities have great potential to increase in the future, and their effects may be widespread. Other uses of the basin's water resources include fishing, hunting and trapping, recreation and tourism.

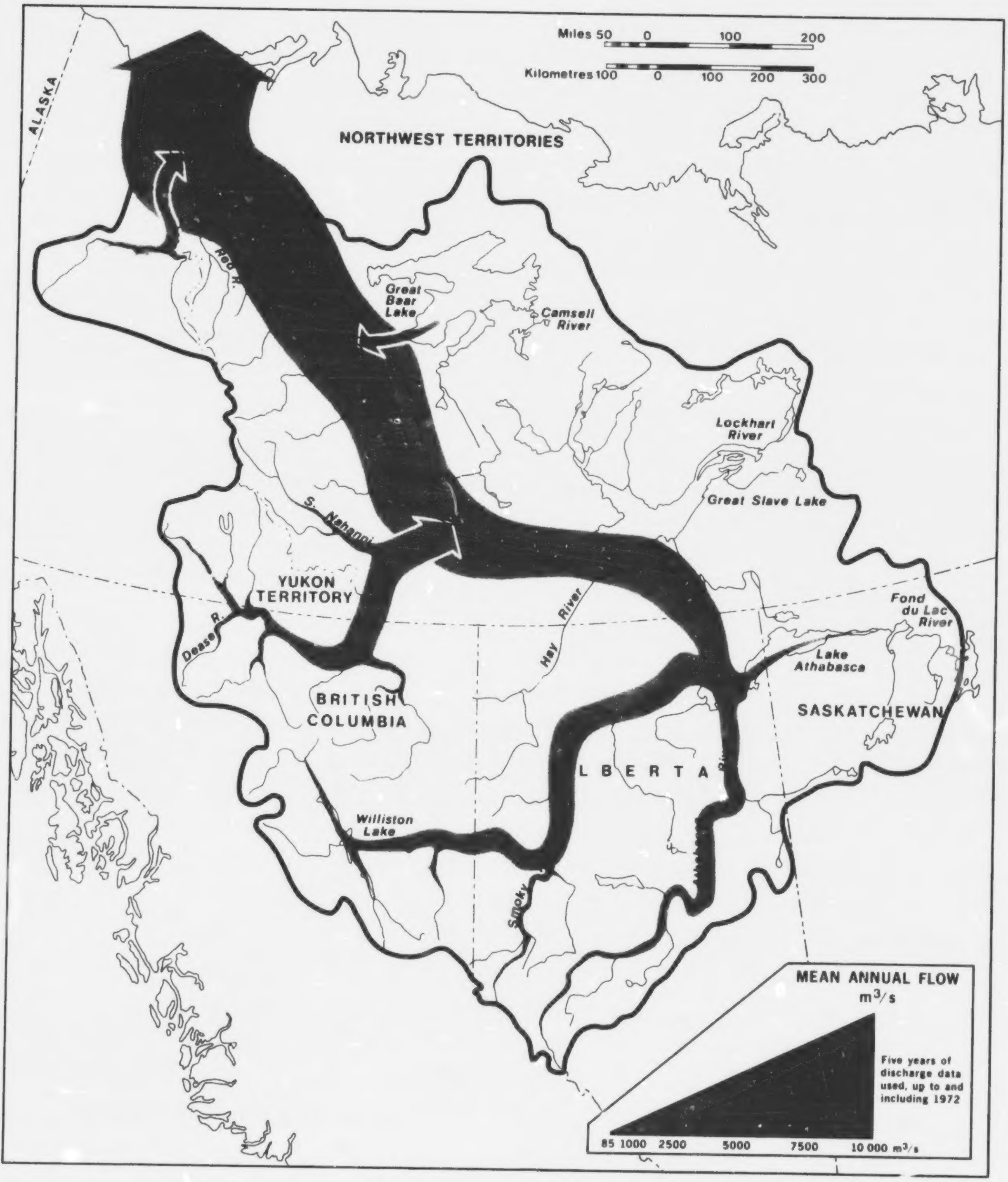
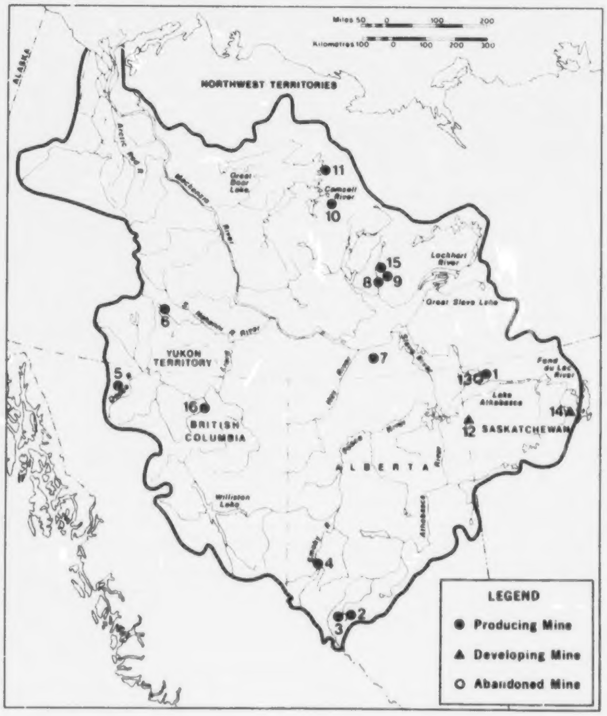


Figure A-6 Mean annual flows in the Mackenzie River basin.

A.3.1 Mining

Mining dates back to the 1920s and has contributed much to the development of the Mackenzie Basin. The lead-zinc mine at Pine Point, about 13 km south of Great Slave Lake, brought the railroad north of the 60th parallel in 1964. The mine also played a crucial role in developing Hay River as a major transfer point and improved the transportation system of the Mackenzie Basin. Other mining operations have contributed to development in similar ways. Major mining activities in the basin today and their principal product are indicated in Figure A-7.

Water contamination by mining activities occurs from tailings, tailing pond discharges and residual processing agents. Potential contaminants include free cyanide, metal-cyanide complexes, copper, lead, zinc, cadmium, arsenic and mercury. Mining increases the concentration of suspended solids downstream from the operation.



LEGEND

No.	Mine	Principal Product
1	Eldorado Nuclear Ltd.	Uranium
2	Cardinal River Coals Ltd.	Coal
3	Churchill Copper	Copper
4	McIntyre Porcupine Limited	Coal
5	Cassiar Asbestos Company Limited	Asbestos
6	Canada Tungsten Mining Co. Ltd.	Tungsten
7	Pine Point Mines	Lead-zinc
8	Giant Yellowknife Mines Limited	Gold
9	Con-Rycon Mine	Gold
10	Terra mining & Exploration Ltd.	Silver-copper
11	Echo Bay Mines	Silver-copper
12	Amok Ltée	Uranium
13	Gunnar Mines Ltd.	Uranium
14	Gulf Minerals Canada's Rabbit Lake Mine	Uranium
15	Camlaren Gold	Gold

Figure A-7 Distribution of mines in the Mackenzie River basin.

The Mackenzie Basin has vast mineral reserves which could lead to further development. There are considerable known reserves of most of the lode minerals presently mined in the Basin (i.e. silver, gold, zinc, nickel, copper, lead, iron, uranium). There are also considerable known reserves of construction materials including marl, limestone, gypsum, asbestos, silica sand, bentonite and pumicite. Of particular note are the vast reserves of coal in the southern section of the basin.

LEGEND: Figure A-8

A. CRUDE OIL – MACKENZIE RIVER BASIN

	Crude Oil Production (million barrels)			
	1965	1973	1965 Cumulative	1973 Cumulative
1. Mitsue	3	18	–	200
2. Swan Hills	20	47	60	750
3. Swan Hills South	7	18	30	400
4. Judy Creek	10	33	42	450
5. Carson Creek North	3	9	7	100
6. Virginia Hills	5	10	18	200
7. Kaybob	3	6	17	100
8. Simonette	2	2	5	–
9. Sturgeon Lake South	4	5	30	150
10. Snipe Lake	4	3	6	80
11. Nipisi	–	19	–	90
12. Rainbow		36		
13. Zama		6		
14. Rainbow South		4		
15. Virgo		3.6		
16. Bound Lake		8.6		
17. Milligan Creek		2		
18. Inga		3		
19. Peejay				
20. Weasel				
21. Fort McMurray		23.7		
22. Norman Wells		1		

B. NATURAL GAS – MACKENZIE RIVER BASIN

	Natural Gas Production (billions of cubic feet or raw gas)		Natural Gas Reserves (trillions of cubic feet)
	1965	Cumulative	
A. Kaybob	15	60	500
B. Windfall	60	200	500
C. Pine Creek	50	150	–
D. Gold Creek	–	–	500
E. Marten Hills	–	–	600
F. Fort St. John			
G. Fort Nelson			
H. Beaver River			
I. Pointed Mountain			

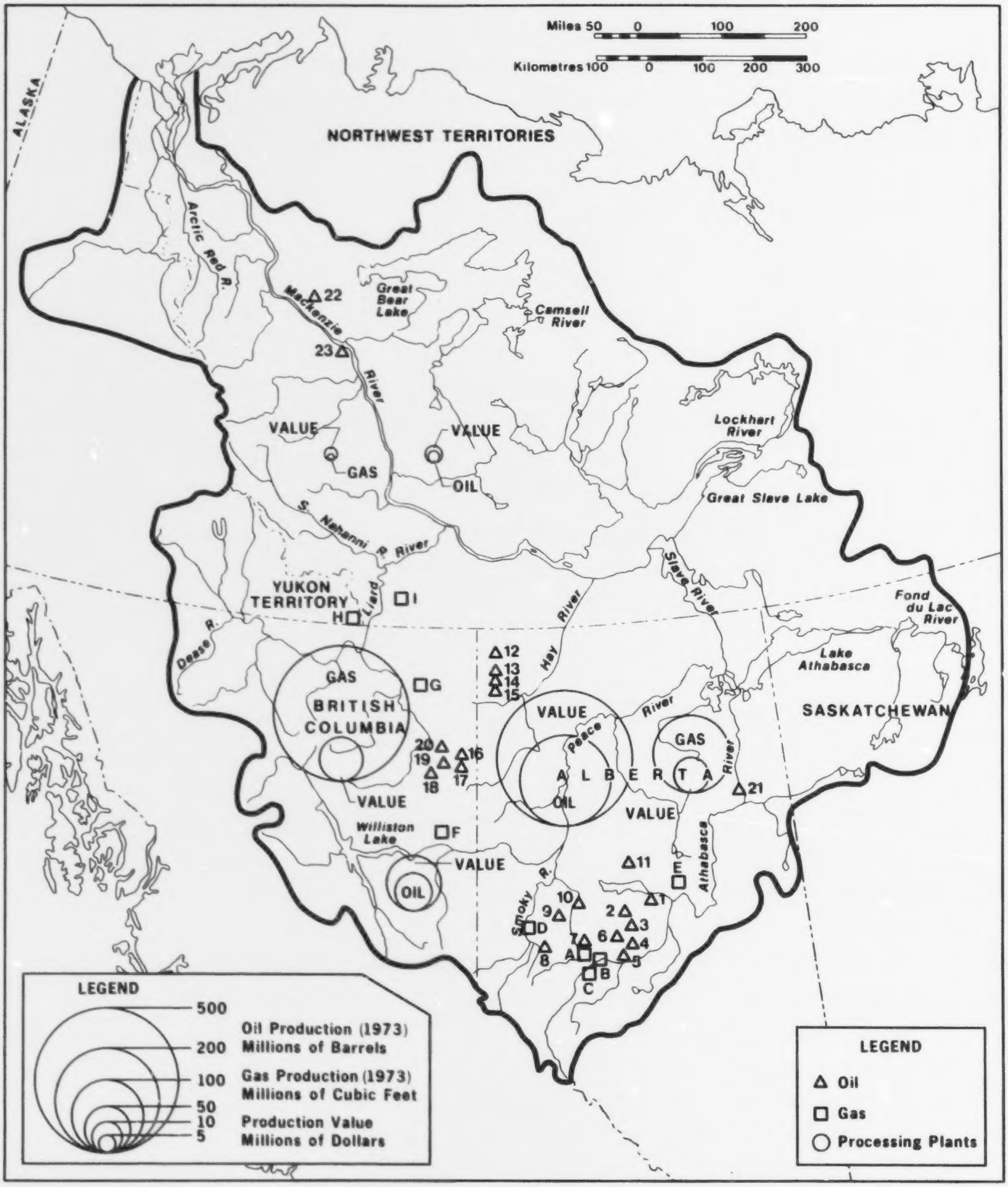


Figure A-8 Oil and gas production and processing plants in the Mackenzie River basin.

A.3.2 Oil and Gas

Oil and gas processing plants are located throughout the basin, with the highest production in Alberta (Fig. A-8). Processing plants in the Peace, Athabasca and Hay River basins account for 85% of Canada's production of oil and gas.

Large quantities of water are required for oil and gas processing. The effluents have higher concentrations of suspended materials and organic substances than the extracted water; this may deleteriously affect the ecology of the downstream waters. A concern related to petroleum development is that of a major spill which could have long-lasting, widespread deleterious effects.

The oil and gas resources of the basin are likely to be increasingly developed. Great potential lies in the heavy oil and tar sand deposits in the Athabasca, Peace and Wabasca River areas. Presently non-producing gas fields exist in the delta area, in the Yukon and in the Beaufort Sea.

A.3.3 Forestry

Utilization of the forest resources of the basin is severely hindered by difficulties of access and transportation costs. Pulp and paper industries are active in the southern portion of the basin but remove only a fraction of the sustained allowable cut. The forest industry can affect water quality by increasing the concentration of suspended material in the water, by increasing the biological oxygen demand and through the addition of contaminants from the processing of timber.

British Columbia produces the greatest amount of wood in the basin. The main commercial species are white and black spruce, lodgepole pine, aspen and balsam.

Tremendous potential exists for future development of the forest resources of the basin. The most rapid expansion of the forest industry is occurring in Alberta, where the provincial government has leased 3.1 million hectares of timberland. The most productive forests in the territorial portions of the basin are in the Liard River valley; these forests will likely be harvested as they have been leased by the Yukon Government.

A.3.4 Agriculture

Agriculture is concentrated in the southern section of the Mackenzie Basin (Fig. A-9). There is 1.1 million hectares of arable land in the Peace and Athabasca watersheds, 1000 hectares of which is irrigated. Mixed farming and wheat production predominate, with lesser amounts of barley, hay and rapeseed. There is some livestock production in the Athabasca subbasin. Agricultural practices affect water quality through the introduction of fertilizers and pesticides and by their effects on erosion patterns; these effects are amplified by irrigation.

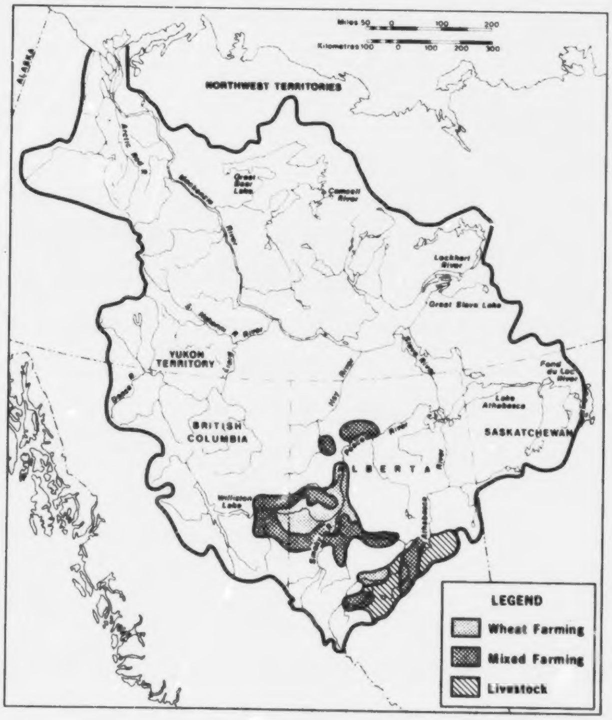


Figure A-9 Farm types in the Mackenzie River basin.

North of the sixtieth parallel, commercial agriculture is not practical due to a lack of precipitation and good soil, and a short growing season. There are a few market gardens and small-scale rapeseed farms near Hay River and Mills Lake. Non-commercial activities include mission gardens at Fort Good Hope, Fort Simpson and Nahanni Butte. Agriculture Canada operates an experimental farm at Fort Simpson.

A.3.5 Urban Facilities

Associated with resource development in the Mackenzie Basin is an increase in the number and size of residential communities. More than 250 000 people live in the basin, largely concentrated in the Peace and Athabasca subbasins.

Most of the communities in the basin obtain their water from surface sources. Sewage, if treated, is processed through a one- or two-stage lagoon system before release to a nearby water course. Water quality may be degraded by inadequate treatment by increases in the concentration of nutrients, dissolved solids, fecal coliforms and heavy metals.

A.3.6 Power Generation

An increase in the demand for electricity in the basin has resulted in the development of hydroelectric and thermal generating facilities. Figure A-10 shows the location of the existing facilities. Hydroelectric generation affects water quality as the reservoirs drastically alter the downstream hydrology. Thermal stations burn fossil fuels; their emissions contain SO_2, polyaromatic hydrocarbons, some heavy metals and other compounds which are potentially toxic to the environment.

A.3.7 Fishing

Domestic and commercial fishing occur throughout the Mackenzie Basin (Fig. A-11). Native populations rely upon fish as a major source

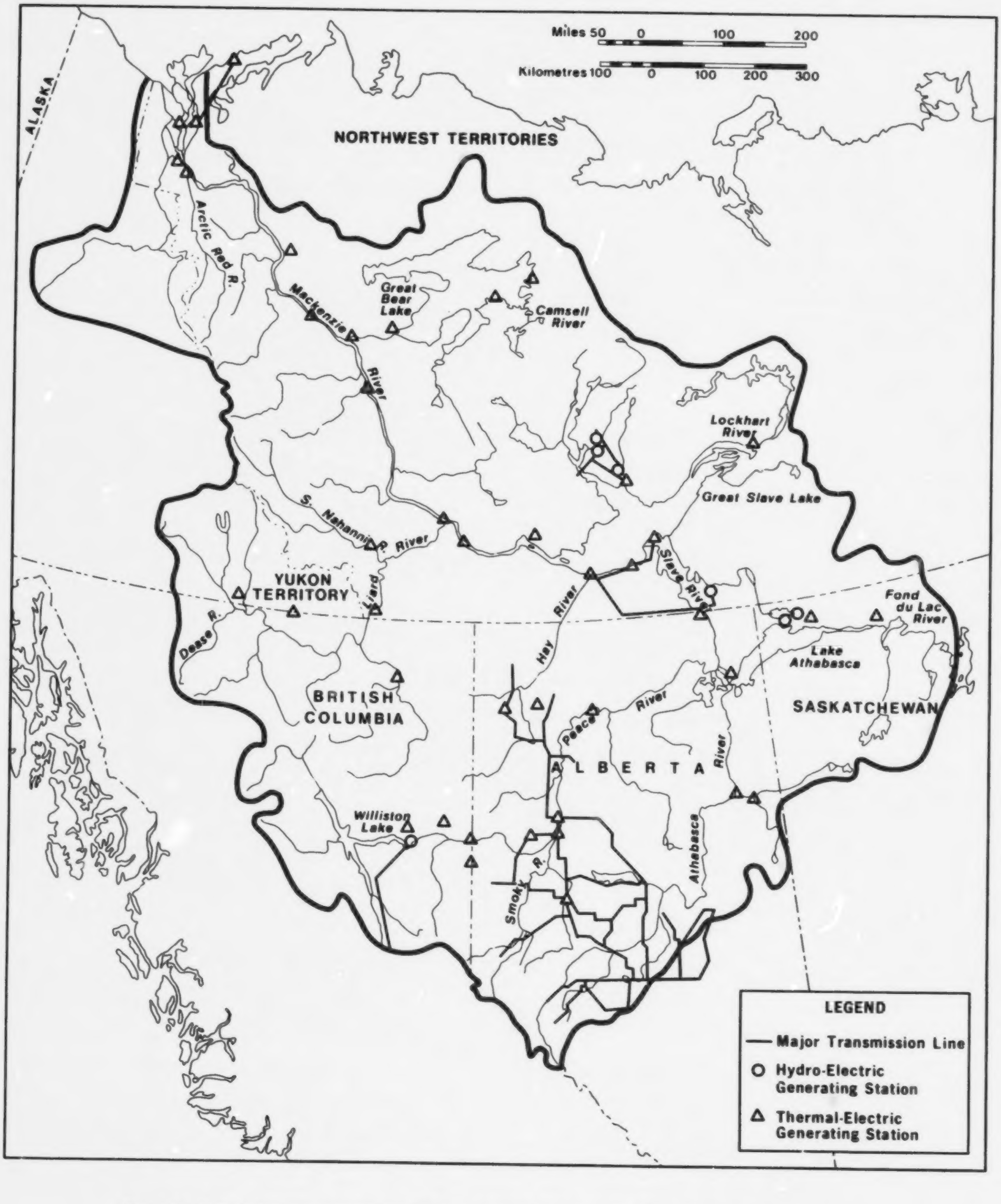


Figure A-10 Existing generating stations and major transmission lines (1975) in the Mackenzie River basin.

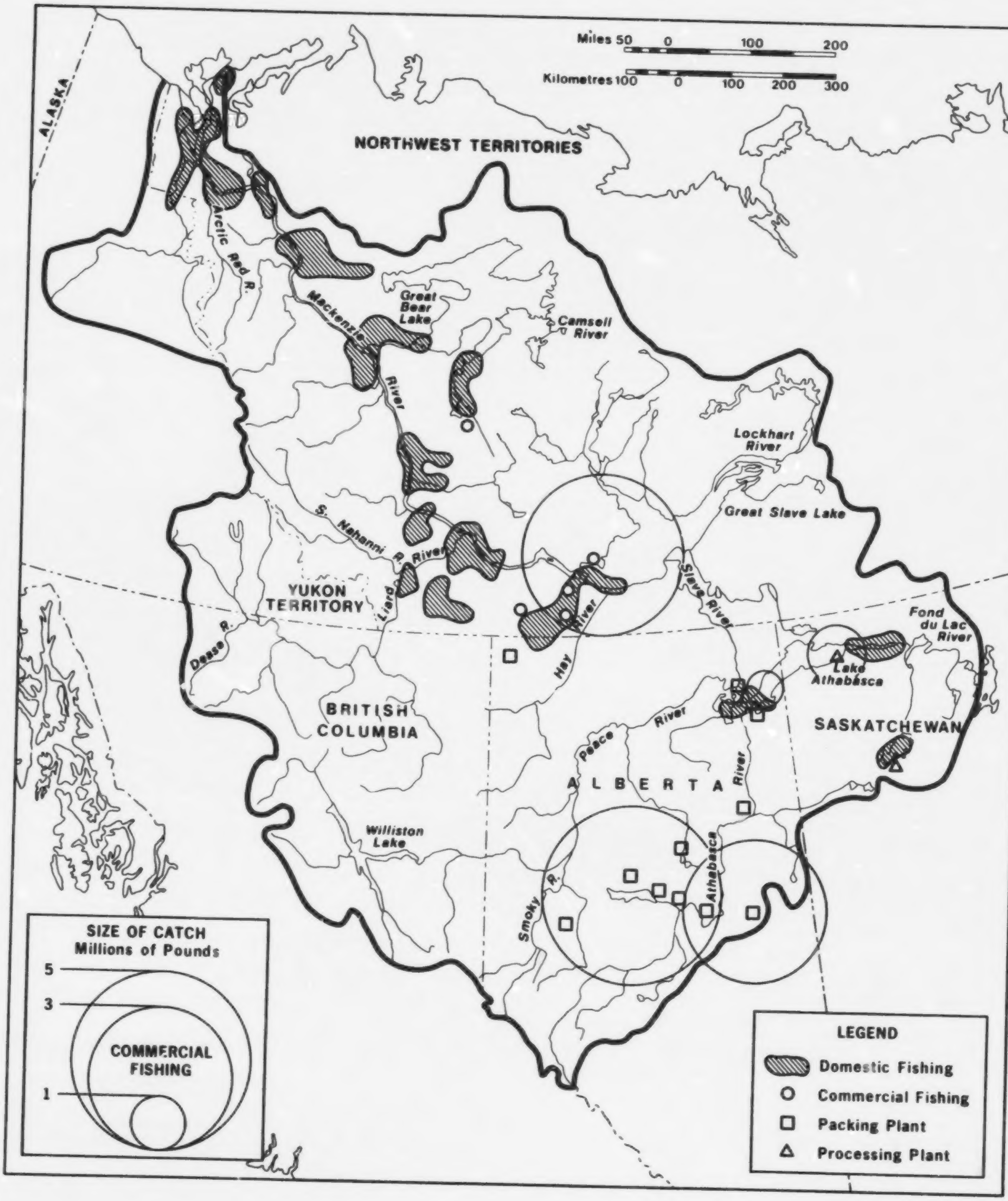


Figure A-11 Fish resource utilization in the Mackenzie River basin.

of protein. Important species harvested are whitefish, inconnu, northern pike, walleye, grayling and lake trout. The greatest harvest of domestic fish along the Mackenzie River is in the delta area.

Lakes in the basin support 160 commercial fishing operations. Important species are walleye, goldeye, northern pike, lake trout, whitefish and inconnu.

A.4 Cultural Factors

A.4.1 Hunting and Trapping

Hunting and trapping are important economic activities to the native people of the basin. The maintenance of a harvestable population relies largely upon preservation of the quality of the environment, of which water is a major part.

Trapping activities are focussed in valleys, lowlands and delta areas. Major trapping species are muskrat, beaver, mink and lynx. Hunting activities are concentrated in the lowlands and Mackenzie Delta. The major species hunted are moose, caribou, bear, waterfowl and game birds. The trapped and hunted harvests are sold for cash and used locally for clothing, food and handicrafts.

A.4.2 Recreation and Tourism

The recreational resources of the basin depend upon the high quality environment and are enhanced by good water quality. Sightseeing, canoeing, hunting, camping, fishing, climbing and skiing are a few of the recreational pursuits. Jasper National Park, Wood Buffalo National Park and Nahanni National Park are located in the basin. A number of sites have also been proposed for protection under the International Biological Program.

A.5 Summary

In the past few decades, man's use of the Mackenzie Basin's mineral, forest, water and petroleum resources has increased dramatically. The development has the potential to alter radically the water quality of the basin. Any degradation in the water quality has the potential to interfere with historical uses made of the basin's resources by its native people and with the recreational uses. To manage competing resource uses effectively, a clear understanding of baseline water quality conditions and of the effects on water quality of the physical, socio-economic and cultural factors is essential.

Appendix B

Frequency of Sampling of Selected Sites in the Mackenzie River Basin

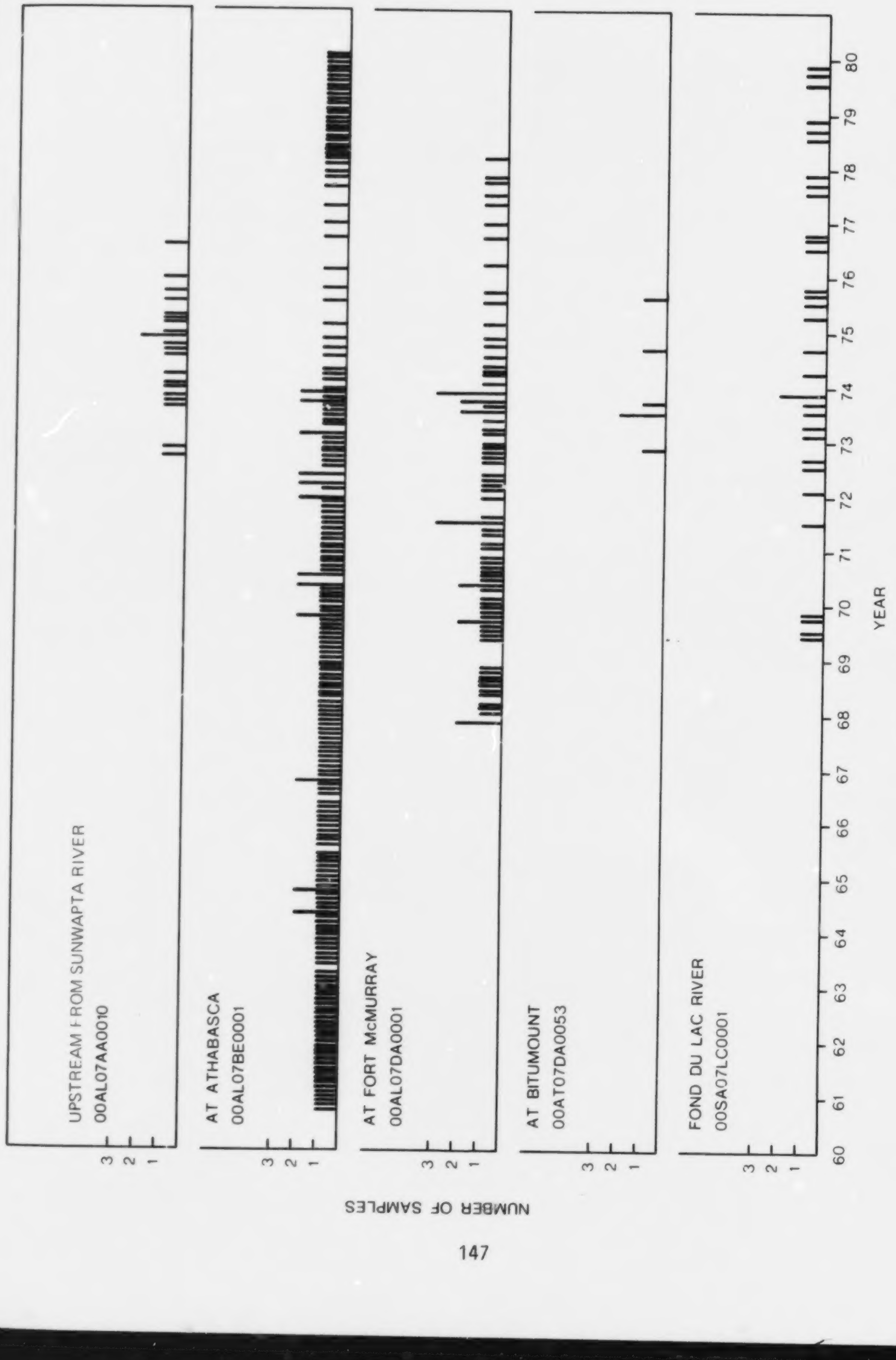
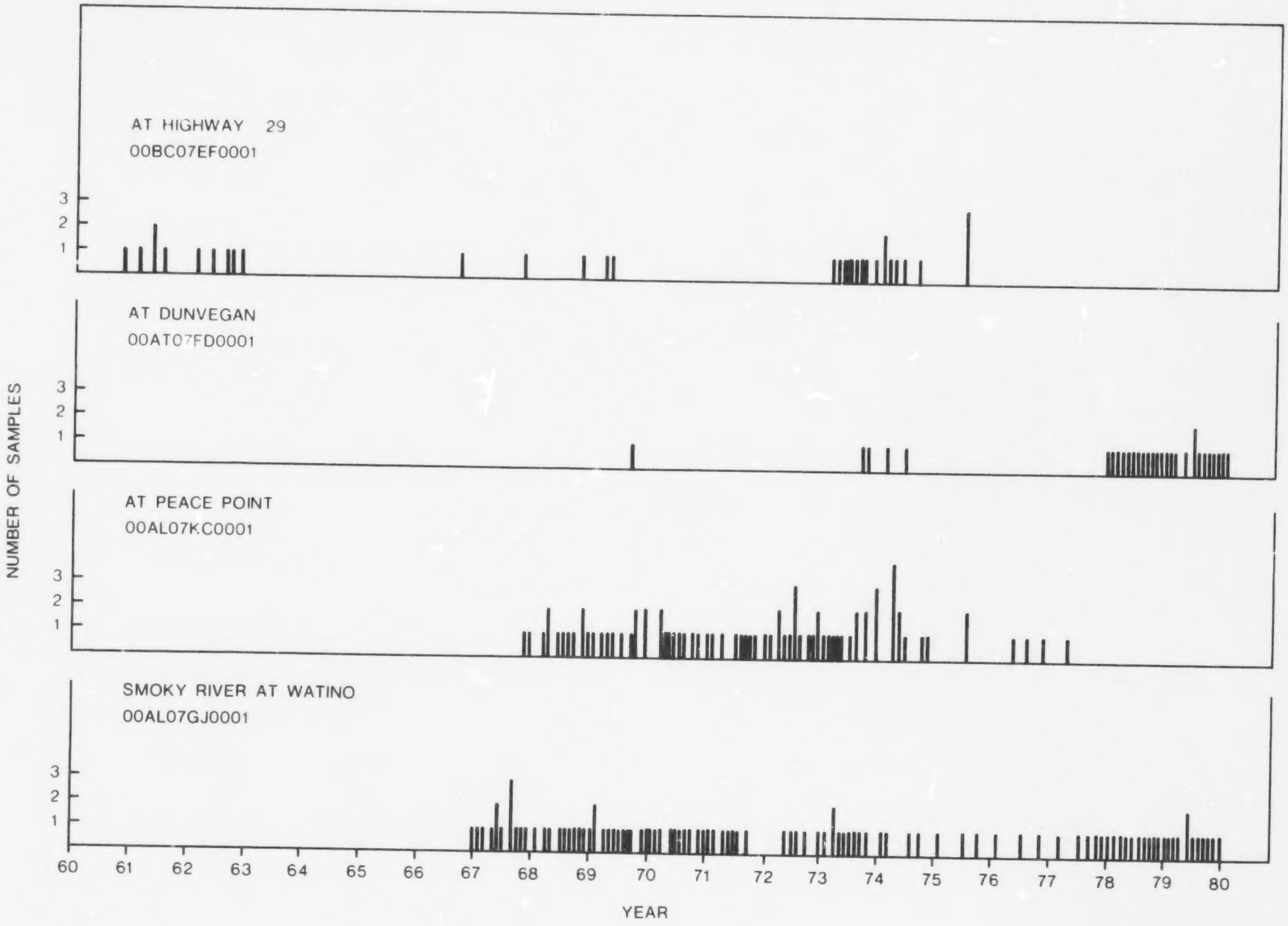


Figure B-1 Athabasca River subbasin.



Fibure B-2 Peace River subbasin.

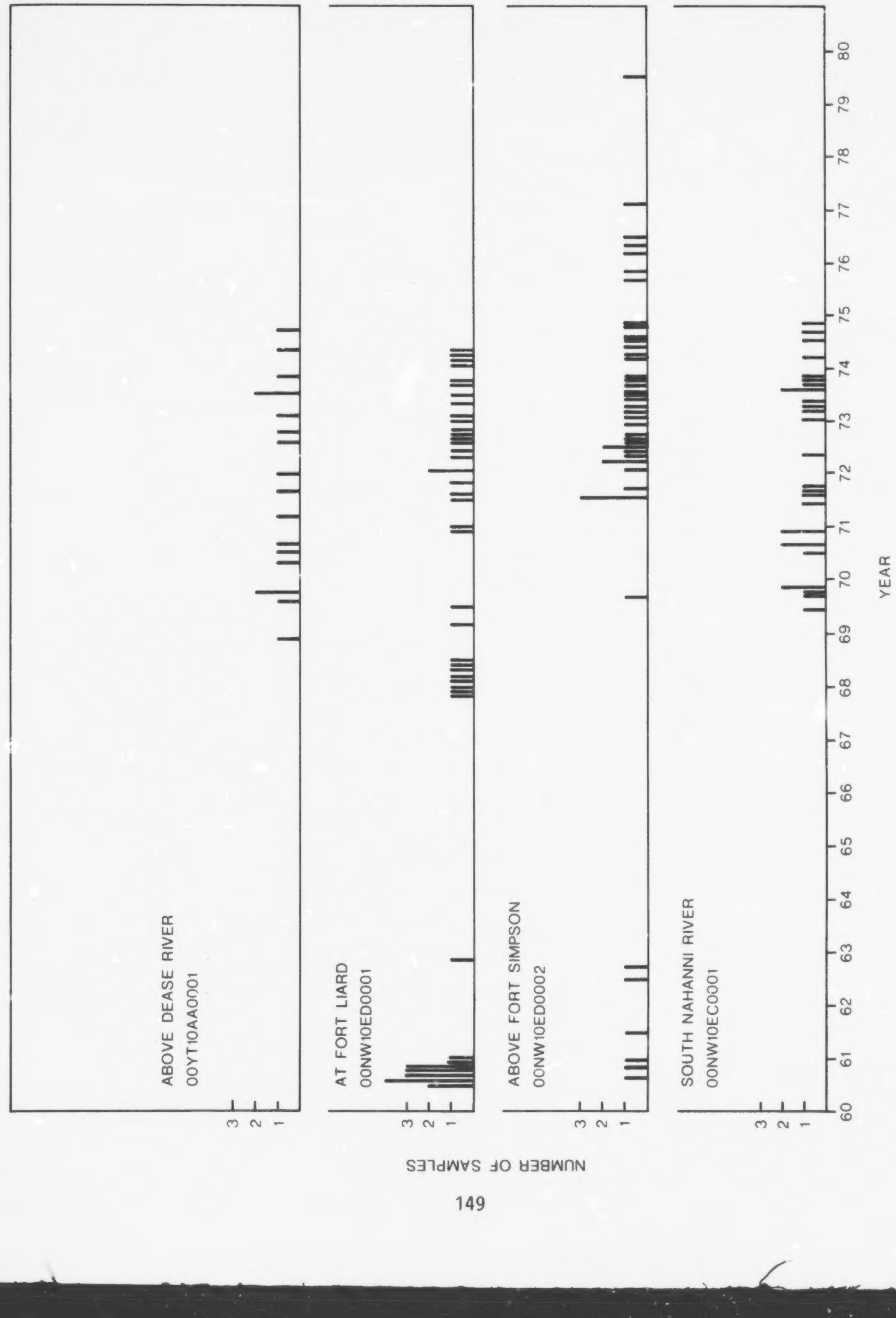


Figure B-3 Liard River subbasin.

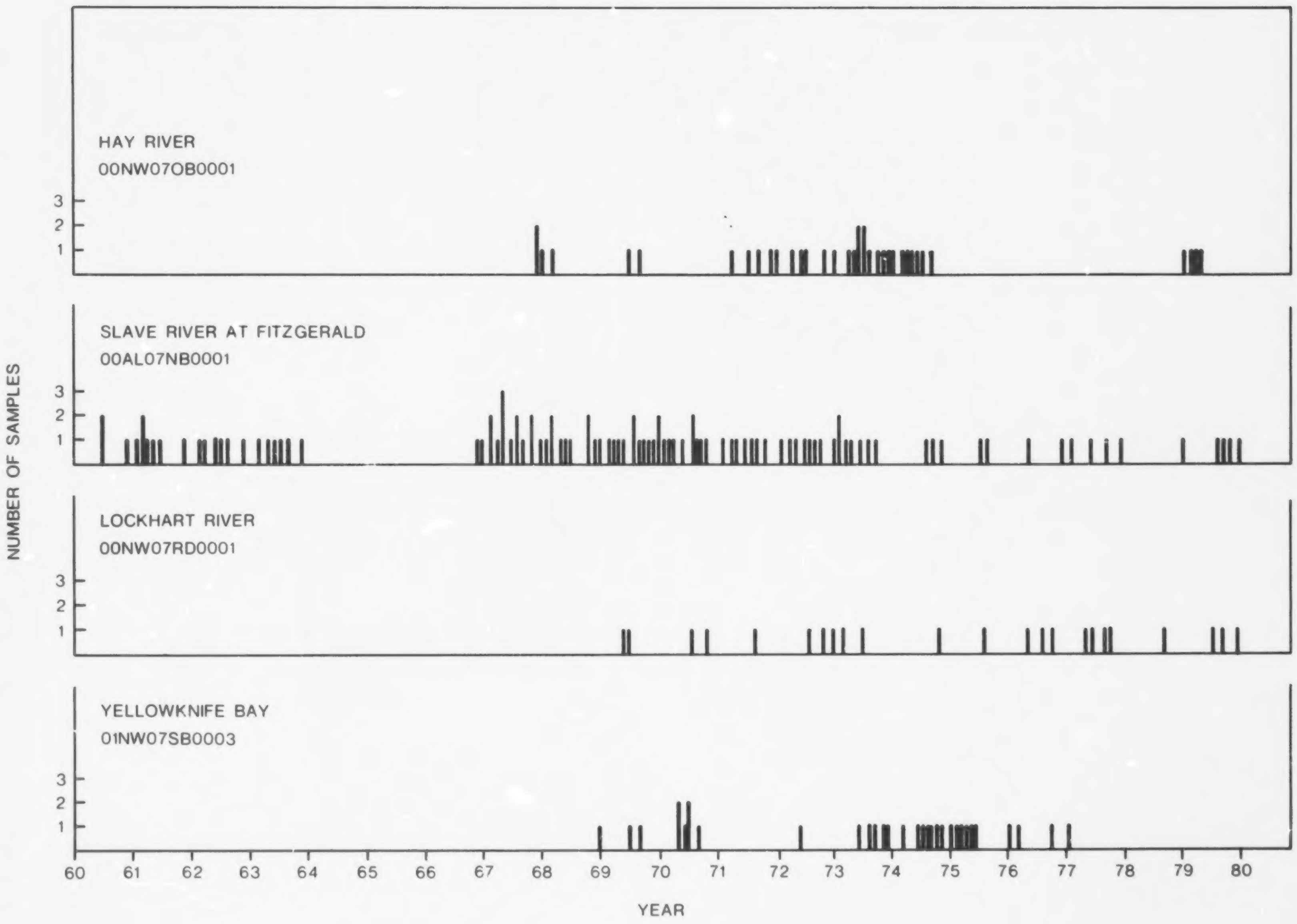
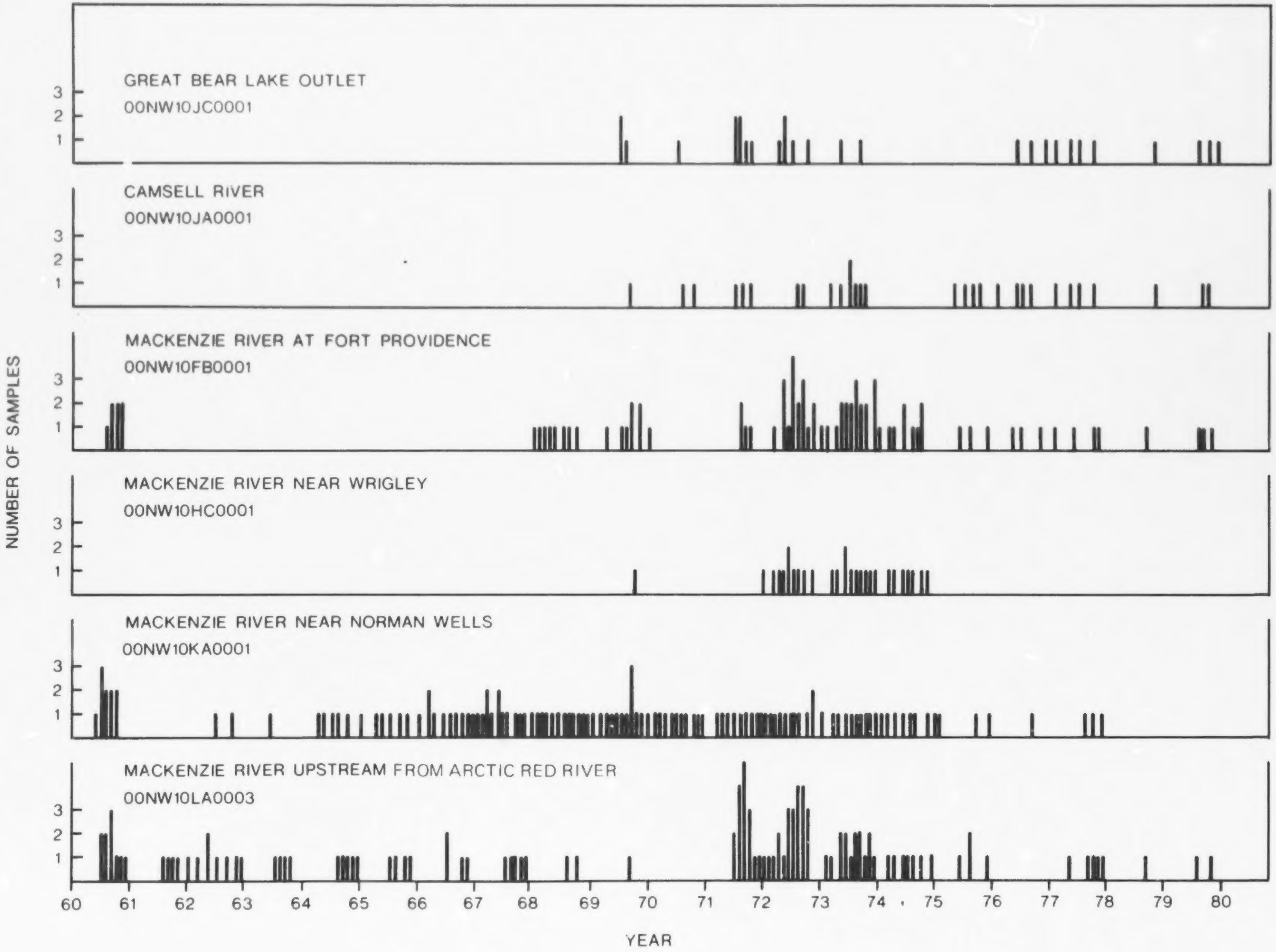


Figure B-4 Hay River and Great Slave Lake subbasins.



Fibure B-5 Great Bear Lake and Mackenzie River subbasins.

Appendix C

Percentiles of Physical Parameters and Major Ions in the Mackenzie River Subbasins

Table C-1a Percentiles of Physical Parameters at Selected Sites in the Athabasca River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
Upstream from Sunwapta	20	24	1.7	88	26	8.0	40	63
At Athabasca	201	33	<0.1	1100	98	7.0	34	74
At Fort McMurray	79	14	4.0	30	15	15		
At Bitumount	5	40	1.0	650	77	22	43	90
Fond du Lac River	31	1.3	0.2	5.6	1.2	1.0	1.7	2.4
TDS (mg L^{-1})								
Upstream from Sunwapta	20	85	52	113	13	86	93	101
At Athabasca	191	169	57	288	48	160	213	234
At Fort McMurray	78	143	117	168	25	143		
At Bitumount	3	164	96	280	48	146	205	241
Fond du Lac River	31	18	12*	28	3	17	19	21
COLOUR (UNITS)								
Upstream from Sunwapta	20	9	5	40	10	5	8	25
At Athabasca	200	29	5	200	26	20	30	60
At Fort McMurray	77	41	<5	200	28	30	60	80
At Bitumount	0							
Fond du Lac River	30	7	<5	20	3	5	10	10
SPECIFIC CONDUCTIVITY (µS cm^{-1})								
Upstream from Sunwapta	20	160	124	217	22	157	172	192
At Athabasca	203	306	117	501	83	292	383	421
At Fort McMurray	79	236	190	270	27	243	248	
At Bitumount	6	295	181	476	81	256	373	427
Fond du Lac River	31	40	26	94	13	37	42	51

* Qualified result (values less than detection limit have been used in the calculation).
n = Number of observations.
S.D. = Standard deviation.

Table C-1b Percentiles of Physical Parameters at Selected Sites in the Peace River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
At HWY 29	32	10	0.1	130	26	1.9	5.0	24
At Dunvegan	28	26	1.2	180	39	10	18	78
At Peace Point	79	54	1.7	330	80	17	52	180
Smoky River at Watino	105	76	1.1	1000	152	35	81	150
TDS (mg L^{-1})								
At HWY 29	31	105	76	306	39	98	101	117
At Dunvegan	17	128	94	233	39	110	138	183
At Peace Point	77	141	98	285	34	131	149	200
Smoky River at Watino	100	181	94	475	74	151	252	279
COLOUR (UNITS)								
At HWY 29	32	11	5	40	8	10	13	20
At Dunvegan	14	25	<5	80	24	13	50	50
At Peace Point	76	67	5	2000	228	30	53	100
Smoky River at Watino	99	49	5	450	60	30	65	100
SPECIFIC CONDUCTIVITY (µS cm^{-1})								
At HWY 29	32	197	148	524	64	185	194	231
At Dunvegan	41	239	177	395	57	225	265	325
At Peace Point	80	257	187	500	55	240	276	332
Smoky River at Watino	105	331	174	781	128	282	451	498

n = Number of observations.
S.D.= Standard deviation.

Table C-1c Percentiles of Physical Parameters at Selected Sites in the Liard River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
Upstream from Dease River	18	9.9	0.2	67	17	2.0	8.0	35
At Fort Liard	48	38	<0.1	330	79	6.5	27	150
Upstream from Fort Simpson	50	95	1.2	600	132	40	150	225
South Nahanni River	28	40	1.3	210	49	22	69	98
TDS (mg L^{-1})								
Upstream from Dease River	17	115	63	216	39	112	132	168
At Fort Liard	45	166	76	280	50	164	205	237
Upstream from Fort Simpson	41	151	90	237	50	132	196	226
South Nahanni River	27	171	88	363	69	143	218	244
COLOUR (UNITS)								
Upstream from Dease River	18	14	<5	60	15	10	15	40
At Fort Liard	34	49	5	300	54	30	80	100
Upstream from Fort Simpson	48	59	<5	350	80	20	75	130
South Nahanni River	25	17	<5	85	19	10	20	50
SPECIFIC CONDUCTIVITY (µS cm^{-1})								
Upstream from Dease River	18	214	124	393	72	218	245	317
At Fort Liard	49	297	144	446	83	286	379	427
Upstream from Fort Simpson	39	287	161	435	90	263	395	420
South Nahanni River	28	320	174	679	129	280	399	480

n = Number of observations.
S.D. = Standard deviation.

Table C-1d Percentiles of Physical Parameters at Selected Sites in the Hay River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
Hay River at mouth	37	45	2.1	225	63	10	43	170
TDS (mg L^{-1})								
Hay River at mouth	30	255	78	527	142	187	400	508
COLOUR (UNITS)								
Hay River at mouth	35	168	30	600	132	130	200	400
SPECIFIC CONDUCTIVITY (μS cm^{-1})								
Hay River at mouth	25	456	217	821	214	367	688	779

n = Number of observations.
S.D. = Standard deviation.

Table C-1e Percentiles of Physical Parameters at Selected Sites in the Great Bear Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
Great Bear Lake outlet	25	3.9	0.3	20	4.8	2.5	5.0	6.4
Camsell River	29	2.1	0.2	7.5	1.8	1.5	2.2	5.5
TDS (mg L^{-1})								
Great Bear Lake outlet	24	79	45	97	10	81	85	90
Camsell River	28	60	44	76	9.0	58	66	74
COLOUR (UNITS)								
Great Bear Lake outlet	25	9.0	<5	75	14	5.0	5.0	10
Camsell River	30	8.0	<5	75	13	5.0	5.0	10
SPECIFIC CONDUCTIVITY (μS cm^{-1})								
Great Bear Lake outlet	24	157	102	214	22	160	169	179
Camsell River	29	116	77	206	23	116	123	133

n = Number of observations.
S.D. = Standard deviation.

Table C-1f Percentiles of Physical Parameters at Selected Sites in the Great Slave Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
Slave River at Fitzgerald	107	91	0.3	1000	163	45	80	180
Lockhart River	22	1.6	0.2	5.5	1.5	1.0	2.0	3.7
Yellowknife Bay	32	5.0	0.3	40	8.8	2.4	4.5	7.5
TDS (mg L^{-1})								
Slave River at Fitzgerald	105	117	24	158	20	117	128	141
Lockhart River	22	8	5*	15	2.0	7.0	9.0	10
Yellowknife Bay	20	131	18	1699	372	38	52	158
COLOUR (UNITS)								
Slave River at Fitzgerald	102	39	<5	350	44	30	50	65
Lockhart River	22	6.0	<5	20	3.0	<5	5.0	5.0
Yellowknife Bay	32	8.0	<5	20	6.0	5.0	10	20
SPECIFIC CONDUCTIVITY ($\mu S\ cm^{-1}$)								
Slave River at Fitzgerald	107	218	50	289	36	221	236	264
Lockhart River	22	16	11	26	3.0	15	17	19
Yellowknife Bay	32	187	20	3351	584	63	100	140

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* Qualified result (values less than detection limit have been used in the calculation).
n = Number of observations.
S.D. = Standard deviation.

Table C-1g Percentiles of Physical Parameters at Selected Sites in the Mackenzie River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TURBIDITY (NTU)								
At Fort Providence	71	8.9	0.4	38	8.1	5.1	13	20
Near Wrigley	28	50	2.6	300	69	30	60	150
Near Norman Wells	129	46	<1	975	100	20	55	106
Upstream from Arctic Red River	109	97	0.4	1000	155	37	110	235
TDS (mg L^{-1})								
At Fort Providence	55	134	82	200	22	129	143	168
Near Wrigley	22	134	105	182	24	129	152	170
Near Norman Wells	128	124	92	320	21	124	130	139
Upstream from Arctic Red River	88	153	96	237	29	148	175	194
COLOUR (UNITS)								
At Fort Providence	71	22	<5	100	17	20	25	40
Near Wrigley	27	51	5.0	500	97	20	50	150
Near Norman Wells	124	82	<5	7100	636	15	30	60
Upstream from Arctic Red River	107	32	<5	275	38	20	40	65
SPECIFIC CONDUCTIVITY ($\mu S\ cm^{-1}$)								
At Fort Providence	59	252	161	815	82	238	265	303
Near Wrigley	18	261	200	342	50	250	298	341
Near Norman Wells	131	235	120	656	55	230	246	263
Upstream from Arctic Red River	99	269	113	411	51	262	308	341

n = Number of observations.
S.D. = Standard deviation.

Table C-2a Percentiles of Major Ions (mg L^{-1})
at Selected Sites in the Athabasca River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
Upstream from Sunwapta	20	0.3	0.1	0.7	0.1	0.3	0.3	0.5
At Athabasca	202	1.5	0.5	13	1.0	1.4	1.8	2.2
At Fort McMurray	78	1.2	1.2	1.3	0.1	1.2		
At Bitumount	2	1.4	0.6	4.0	0.6	1.2	1.8	2.0
Fond du Lac River	31	0.7	0.3	1.4	0.2	0.7	0.7	0.9
Na^+								
Upstream from Sunwapta	20	0.6	0.2	1.1	0.2	0.6	0.8	1.0
At Athabasca	202	7.8	2.2	20	3.5	7.2	11	12
At Fort McMurray	78	10	7.0	15	3.6	9.0	13	
At Bitumount	5	9.9	3.6	21	4.6	8.4	14	16
Fond du Lac River	31	1.6	1.1	3.6	0.5	1.5	1.7	1.9
Ca^{2+}								
Upstream from Sunwapta	20	23	13	32	3.6	23	25	26
At Athabasca	202	42	17	68	10	39	50	55
At Fort McMurray	68	33	22	40	8.1	35	39	
At Bitumount	4	41	21	67	11	37	50	57
Fond du Lac River	31	3.9	2.4	7.1	1.1	3.7	4.5	5.1
Mg^{2+}								
Upstream from Sunwapta	16	6.3	2.8	11	2.3	5.7	8.0	10
At Athabasca	133	11	3.5	20	3.4	11	14	16
At Fort McMurray	23	6.5	4.0	8.0	1.4	7.0	7.0	
At Bitumount	6	9.8	4.3	15	2.8	8.7	12	14
Fond du Lac River	9	1.1	0.1	2.1	0.5	1.0	1.1	
CO_3^{2-}								
Upstream from Sunwapta	20	0	0	0	0	0	0	
At Athabasca	190	0	0	0	0	0	0	0
At Fort McMurray	75	0	0	0	0	0	0	
At Bitumount	6	0	0	0	0	0	0	0
Fond du Lac River	24	0	0	0	0	0	0	0
HCO_3^-								
Upstream from Sunwapta	20	86	49	114	14	87	94	99
At Athabasca	190	152	48	234	37	146	187	201
At Fort McMurray	75	104	60	138	26	105	117	
At Bitumount	6	144	78	228	38	133	180	200
Fond du Lac River	24	13	10	21	2	12	13	16

Table C-2a Continued

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
Cl^-								
Upstream from Sunwapta	20	0.4	0.1	0.8	0.2	0.3	0.5	0.7
At Athabasca	202	3.2	0.2	10	2.2	2.4	4.8	6.0
At Fort McMurray	79	9.1	6.0	15	3.4	8.0	11	
At Bitumount	6	4.3	0.6	41	5.5	2.6	5.3	7.5
Fond du Lac River	31	3.2	0.5	5.9	1.4	3.1	4.1	5.0
SO_4^{2-}								
Upstream from Sunwapta	20	12	5.3	19	3.5	11	15	16
At Athabasca	170	29	8.0	58	12	27	39	47
At Fort McMurray	78	32	17	49	12	30	37	
At Bitumount	6	29	8.8	56	11	26	37	44
Fond du Lac River	15	1.5	<1.0	2.4	0.5	1.3	2.1	2.3

n = Number of observations.
S.D. = Standard deviation.

Table C-2b Percentiles of Major Ions (mg L^{-1}) at Selected Sites in the Peace River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
At HWY 29	31	0.6	0.2	1.3	0.2	0.5	0.6	0.7
At Dunvegan	41	1.3	0.4	10	1.7	0.8	1.3	2.2
At Peace Point	78	1.1	0.1	3.4	0.7	0.9	1.2	2.3
Smoky River at Watino	104	1.0	0.1	3.9	0.7	0.9	1.2	1.7
Na^+								
At HWY 29	32	1.5	0.7	8.3	1.4	1.2	1.5	2.0
At Dunvegan	41	3.8	<1	19	3.8	3.0	4.0	7.0
At Peace Point	79	4.6	0.4	19	2.4	4.3	5.0	6.6
Smoky River at Watino	103	8.3	0.4	34	6.6	6.7	12	19
Ca^{2+}								
At HWY 29	32	30	20	74	8.9	28	30	33
At Dunvegan	20	32	21	50	5.5	31	32	37
At Peace Point	78	38	20	63	7.6	35	41	50
Smoky River at Watino	105	47	25	104	17	41	62	69
Mg^{2+}								
At HWY 29	11	7.9	4.6	24	5.5	6.9	7.3	9.2
At Dunvegan	41	8.4	3.0	23	3.5	7.0	10	12
At Peace Point	78	7.6	2.0	18	3.1	6.9	8.7	11
Smoky River at Watino	59	12	4.3	29	5.1	10	16	18
CO_3^{2-}								
At HWY 29	32	0	0	4	1	0	0	0
At Dunvegan	34	0	0	5	1	0	0	0
At Peace Point	75	0	0	0	0	0	0	0
Smoky River at Watino	99	0	0	3	0	0	0	0
HCO_3^-								
At HWY 29	32	112	82	304	37	104	110	117
At Dunvegan	34	125	94	161	18	123	135	152
At Peace Point	75	122	90	219	23	118	130	151
Smoky River at Watino	99	155	82	378	55	135	195	232
Cl^-								
At HWY 29	32	0.6	0.1	5.6	0.9	0.4	0.6	0.8
At Dunvegan	43	2.3	0.0	11	2.6	<1	3.0	6.0
At Peace Point	78	2.3	0.6	9.9	1.7	1.8	2.6	4.3
Smoky River at Watino	105	36	8.8	99	21	30	53	67

Table C-2b Continued

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
SO_4^{2-}								
At HWY 29	32	11	6.7	44	6.4	9.5	11	13
At Dunvegan	43	25	8.0	108	22	16	35	58
At Peace Point	78	26	9.6	67	12	24	32	45
Smoky River at Watino	104	3.3	0.2	29	4.9	1.5	2.8	10

n = Number of observations.
S.D. = Standard deviation.

Table C-2c Percentiles of Major Ions (mg L^{-1}) at Selected Sites in the Liard River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
Upstream from Dease River	17	0.7	0.5	1.9	0.3	0.6	0.7	0.9
At Fort Liard	49	1.2	0.4	2.4	0.5	1.0	1.5	2.0
Upstream from Fort Simpson	46	0.9	0.5	3.8	0.5	0.8	1.0	1.2
South Nahanni River	28	1.2	0.4	8.2	1.6	0.7	1.0	3.3
Na^+								
Upstream from Dease River	17	1.6	0.8	4.6	0.9	1.3	1.7	2.3
At Fort Liard	60	4.3	0.7	12.3	2.8	3.2	5.4	8.9
Upstream from Fort Simpson	46	2.8	1.2	7.2	1.4	2.3	4.1	4.7
South Nahanni River	33	6.0	0.4	55	12.5	1.2	1.8	18.8
Ca^{2+}								
Upstream from Dease River	17	33	20	59	9.9	31	39	44
At Fort Liard	60	42	20	78	13	38	53	61
Upstream from Fort Simpson	50	42	27	66	12	38	56	60
South Nahanni River	32	42	21	78	14	38	50	64
Mg^{2+}								
Upstream from Dease River	0							
At Fort Liard	26	9.9	4.6	17	3.0	9.7	11	13
Upstream from Fort Simpson	10	9.2	6.6	17	3.4	7.9	11	14
South Nahanni River	6	8.2	5.2	11	2.2	8.8	9.5	
CO_3^{2-}								
Upstream from Dease River	17	0	0	2	1	0	0	0
At Fort Liard	45	0	0	3	0	0	0	0
Upstream from Fort Simpson	40	0	0	1	0	0	0	0
South Nahanni River	25	0	0	1	0	0	0	1
HCO_3^-								
Upstream from Dease River	17	126	61	265	50	124	144	195
At Fort Liard	45	150	61	233	45	150	189	215
Upstream from Fort Simpson	40	138	77	255	50	121	201	210
South Nahanni River	25	126	86	199	35	116	149	190
Cl^-								
Upstream from Dease River	17	0.3	<0.1	1.2	0.3	0.2	0.4	0.7
At Fort Liard	58	1.6	0.2	8.6	1.2	1.3	1.8	2.6
Upstream from Fort Simpson	50	1.8	0.4	7.5	1.5	1.2	2.7	3.5
South Nahanni River	33	10	0.0	117	27	0.9	1.3	38

Table C-2c Continued

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
SO_4^{2-}								
Upstream from Dease River	17	10	4.2	31	5.8	9.0	10	11
At Fort Liard	58	30	7.4	60	12	26	40	47
Upstream from Fort Simpson	50	29	7.7	46	9.3	26	37	41
South Nahanni River	33	33	13	65	13	30	41	49

n = Number of observations.
S.D. = Standard deviation.

Table C-2d Percentiles of Major Ions (mg L^{-1}) at Selected Sites in the Hay River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
Hay River at mouth	36	2.7	1.2	8.6	1.2	2.5	3.2	3.5
Na^+								
Hay River at mouth	36	16	5.4	36	9.4	12	23	33
Ca^{2+}								
Hay River at mouth	33	65	29	131	32	51	99	108
Mg^{2+}								
Hay River at mouth	27	12	2.4	29	7.4	9.9	17	23
CO_3^{2-}								
Hay River at mouth	30	1.0	0.0	13	3.0	0.0	0.0	5.0
HCO_3^-								
Hay River at mouth	30	149	2.0	333	90	114	256	295
Cl^-								
Hay River at mouth	36	5.5	1.4	15	4.1	3.5	8.6	13
SO_4^{2-}								
Hay River at mouth	37	84	33	178	43	68	112	160

n = Number of observations.
S.D. = Standard deviation.

Table C-2e Percentiles of Major Ions (mg L^{-1})
at Selected Sites in the Great Bear Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
Great Bear Lake outlet	28	0.7	0.5	1.0	0.1	0.7	0.8	0.8
Camsell River	30	0.9	0.6	2.5	0.3	0.9	1.0	1.1
Na^+								
Great Bear Lake outlet	28	3.9	2.7	5.5	0.7	3.8	4.2	4.6
Camsell River	30	1.9	1.2	2.8	0.4	1.9	2.1	2.5
Ca^{2+}								
Great Bear Lake outlet	27	16	8.4	24	3.1	17	19	20
Camsell River	28	14	10	18	2.1	14	16	17
Mg^{2+}								
Great Bear Lake outlet	7	6.9	6.0	8.1	0.7	6.7	7.4	
Camsell River	4	5.6	5.1	6.0	0.4	5.7	5.9	
CO_3^{2-}								
Great Bear Lake outlet	21	0	0	0	0	0	0	0
Camsell River	20	0	0	0	0	0	0	0
HCO_3^-								
Great Bear Lake outlet	21	66	28	110	14	68	70	74
Camsell River	20	53	43	66	7.0	50	57	64
Cl^-								
Great Bear Lake outlet	28	4.7	3.6	7.1	0.7	4.7	5.0	5.5
Camsell River	30	2.1	1.4	3.0	0.4	2.1	2.3	2.6
SO_4^{2-}								
Great Bear Lake outlet	28	15	8.6	30	3.9	14	15	17
Camsell River	30	9.9	0.6	21	3.6	9.8	12	14

n = Number of observations.
S.D. = Standard deviation.

Table C-2f Percentiles of Major Ions (mg L^{-1}) at Selected Sites in the Great Slave Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
Slave River at Fitzgerald	107	1.1	0.5	2.4	0.4	1.0	1.2	1.7
Lockhart River	22	0.4	<0.1	0.6	0.1	0.4	0.4	0.5
Yellowknife Bay	24	1.5	0.2	14	2.7	0.9	1.0	1.8
Na^+								
Slave River at Fitzgerald	106	6.3	1.2	12	2.0	6.3	7.5	9.1
Lockhart River	22	0.5	<0.1	0.8	0.2	0.5	0.5	0.6
Yellowknife Bay	24	15	1.0	264	54	2.7	3.5	6.5
Ca^{2+}								
Slave River at Fitzgerald	107	29	5.5	42	6.0	29	33	36
Lockhart River	22	1.9	0.6	8.2	1.6	1.3	2.4	3.7
Yellowknife Bay	32	17	1.9	282	49	7.2	12	15
Mg^{2+}								
Slave River at Fitzgerald	28	6.8	5.3	8.9	0.8	6.7	7.3	7.6
Lockhart River	3	0.6	0.4	0.8	0.2	0.6		
Yellowknife Bay	7	3.4	1.1	7.2	2.5	2.4	6.8	
CO_3^{2-}								
Slave River at Fitzgerald	106	0	0	0	0	0	0	0
Lockhart River	18	0	0	0	0	0	0	0
Yellowknife Bay	18	0	0	0	0	0	0	0
HCO_3^-								
Slave River at Fitzgerald	106	100	16	141	18	102	113	117
Lockhart River	18	5.0	1.0	12*	2.0	5.0	6.0	8.0
Yellowknife Bay	18	33	15	114	23	29	37	59
Cl^-								
Slave River at Fitzgerald	107	5.7	<0.1	16	2.9	5.5	7.4	9.2
Lockhart River	22	0.4	<0.1	0.8	0.1	0.4	0.5	0.6
Yellowknife Bay	24	36	0.9	706	144	3.4	5.3	8.8
SO_4^{2-}								
Slave River at Fitzgerald	107	19	3.9	51	5.4	19	22	24
Lockhart River	22	1.3	<1	2.9	0.5	1.3	1.6	1.6
Yellowknife Bay	22	24	2.4	335	70	5.8	11	23

* Qualified result (values less than detection limit have been used in the calculation).
n = Number of observations.
S.D. = Standard deviation.

Table C-2g Percentiles of Major Ions (mg L^{-1}) at Selected Sites in the Mackenzie River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
K^+								
At Fort Providence	86	1.3	0.6	8.7	0.8	1.2	1.3	1.6
Near Wrigley	27	1.0	0.7	1.5	0.2	1.0	1.0	1.2
Near Norman Wells	131	0.9	0.6	4.5	0.4	0.9	1.0	1.0
Upstream from Arctic Red River	106	1.0	0.6	4.3	0.4	1.0	1.1	1.3
Na^+								
At Fort Providence	86	7.1	2.2	18	1.8	7.2	7.7	8.4
Near Wrigley	27	7.7	3.1	17	3.4	6.1	9.7	13
Near Norman Wells	131	8.3	1.7	49	5.0	7.3	9.5	12
Upstream from Arctic Red River	105	7.6	1.6	67	6.5	6.6	9.2	11
Ca^{2+}								
At Fort Providence	84	32	24	50	5.8	31	35	42
Near Wrigley	28	33	27	48	5.2	33	36	42
Near Norman Wells	132	28	<5	69	5.2	28	30	31
Upstream from Arctic Red River	119	35	17	56	5.5	35	39	42
Mg^{2+}								
At Fort Providence	50	6.5	2.9	10	1.7	6.5	7.4	8.8
Near Wrigley	0							
Near Norman Wells	34	7.6	5.9	11	1.1	7.8	8.3	8.9
Upstream from Arctic Red River	61	8.2	3.2	18	2.8	8.0	9.1	12
CO_3^{2-}								
At Fort Providence	57	0	0	0	0	0	0	0
Near Wrigley	22	0	0	0	0	0	0	0
Near Norman Wells	123	0	0	0	0	0	0	0
Upstream from Arctic Red River	97	0	0	0	0	0	0	0
HCO_3^-								
At Fort Providence	57	104	34	160	21	102	114	128
Near Wrigley	22	106	83	146	19	98	111	138
Near Norman Wells	123	94	75	149	10	93	100	103
Upstream from Arctic Red River	97	112	77	161	14	112	123	128

Table C-2g Continued

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
Cl^-								
At Fort Providence	85	7.0	0.3	19	3.1	7.5	8.4	9.2
Near Wrigley	27	8.9	2.2	24	5.1	8.0	10	16
Near Norman Wells	130	9.3	1.0	55	5.1	8.7	10	13
Upstream from Arctic Red River	120	7.9	0.4	61	6.4	6.8	9.5	15
SO_4^{2-}								
At Fort Providence	71	25	8.7	90	9.3	23	26	32
Near Wrigley	27	26	18	34	4.7	26	28	33
Near Norman Wells	130	24	16	74	5.5	24	26	28
Upstream from Arctic Red River	109	35	18	82	14	31	39	61

n = Number of observations.
S.D. = Standard deviation.

Appendix D

Seasonal Variation of Major Ions at Selected Sites in the Mackenzie River Subbasins

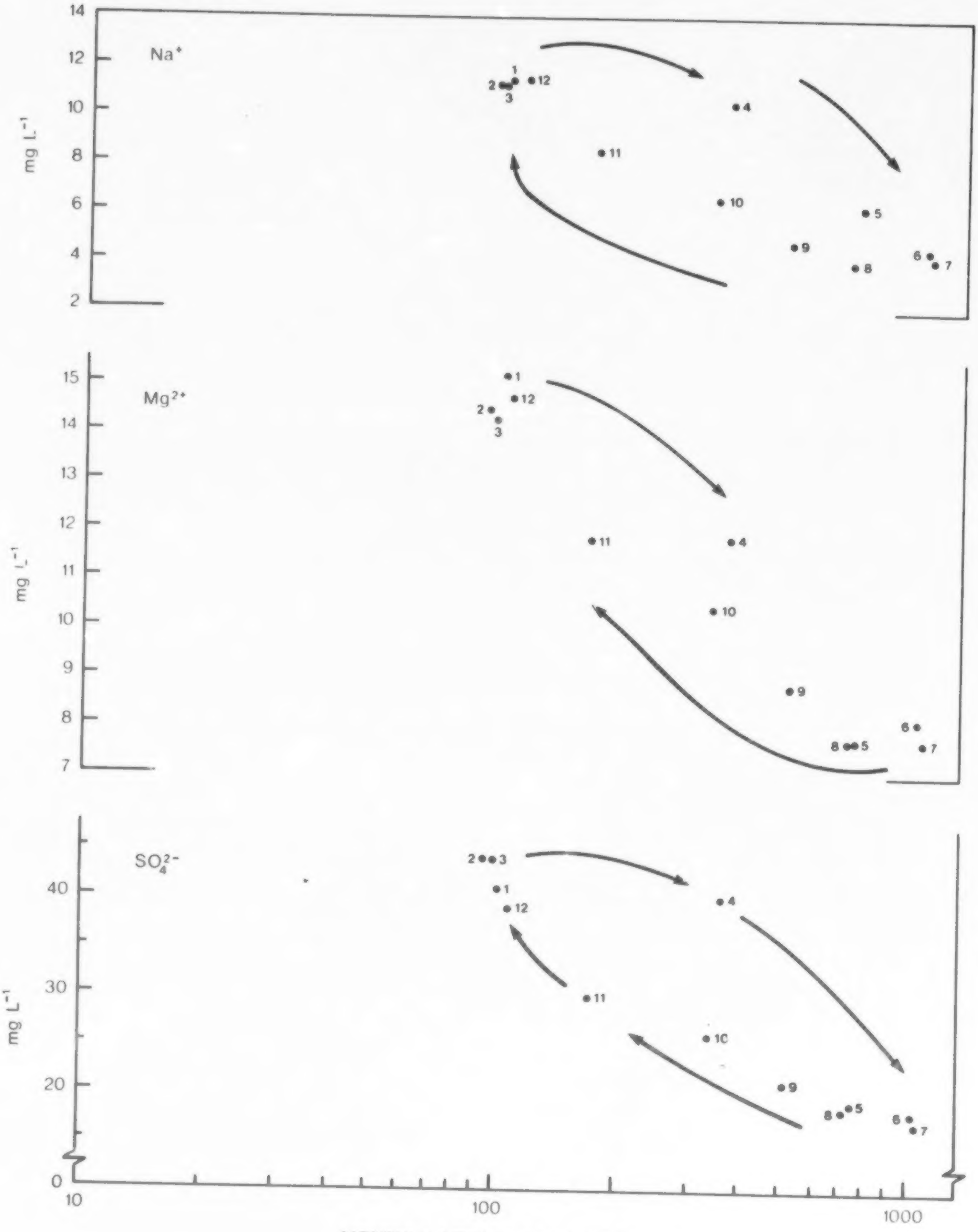

Figure D-1 Seasonal variation of Na^+, Mg^{2+} and $SO_4{}^{2-}$ at Athabasca River at Athabasca (00AL07BE0001). Numbers refer to month of the year.

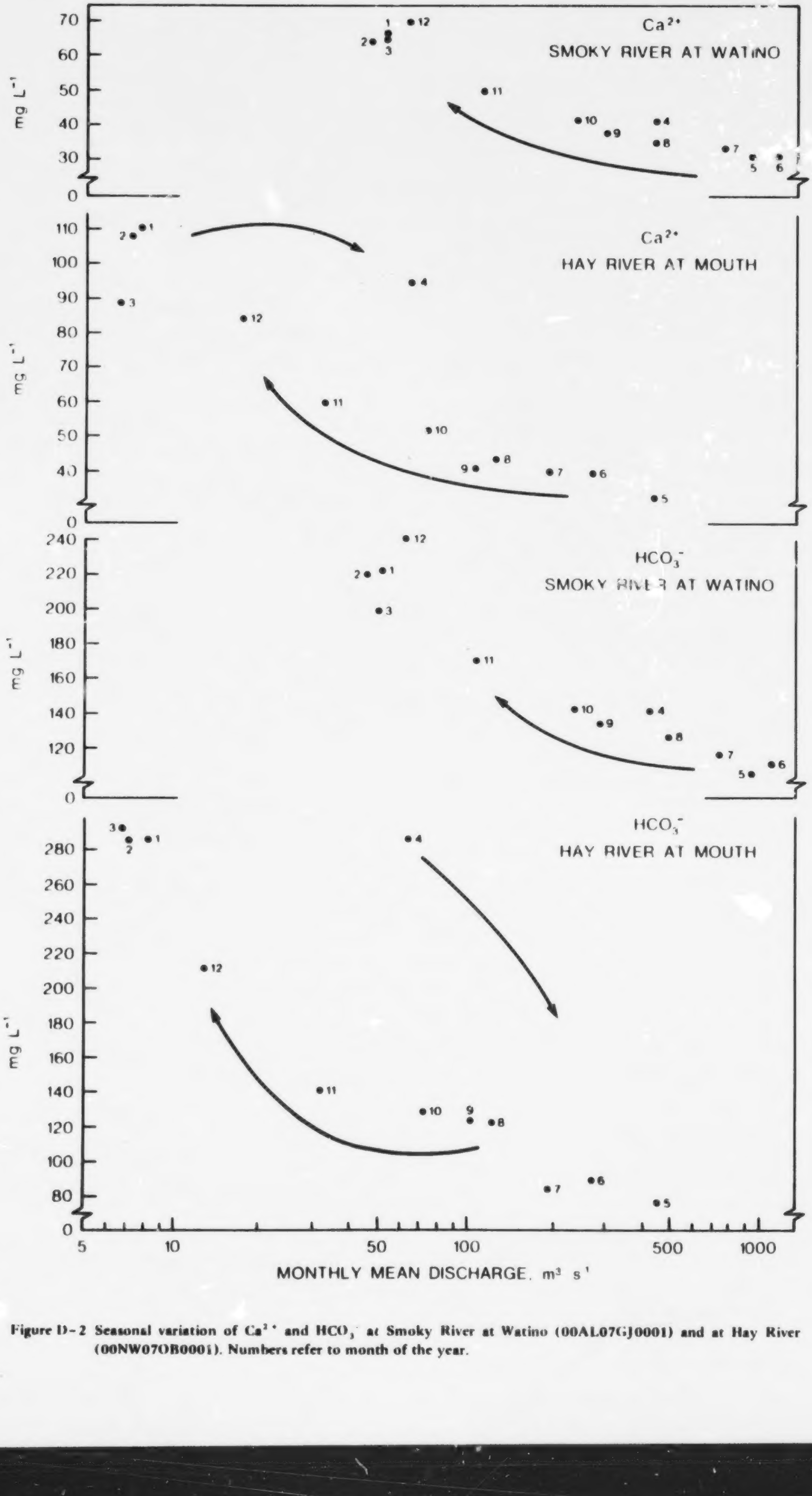

Figure D-2 Seasonal variation of Ca^{2+} and HCO_3^- at Smoky River at Watino (00AL07GJ0001) and at Hay River (00NW07OB0001). Numbers refer to month of the year.

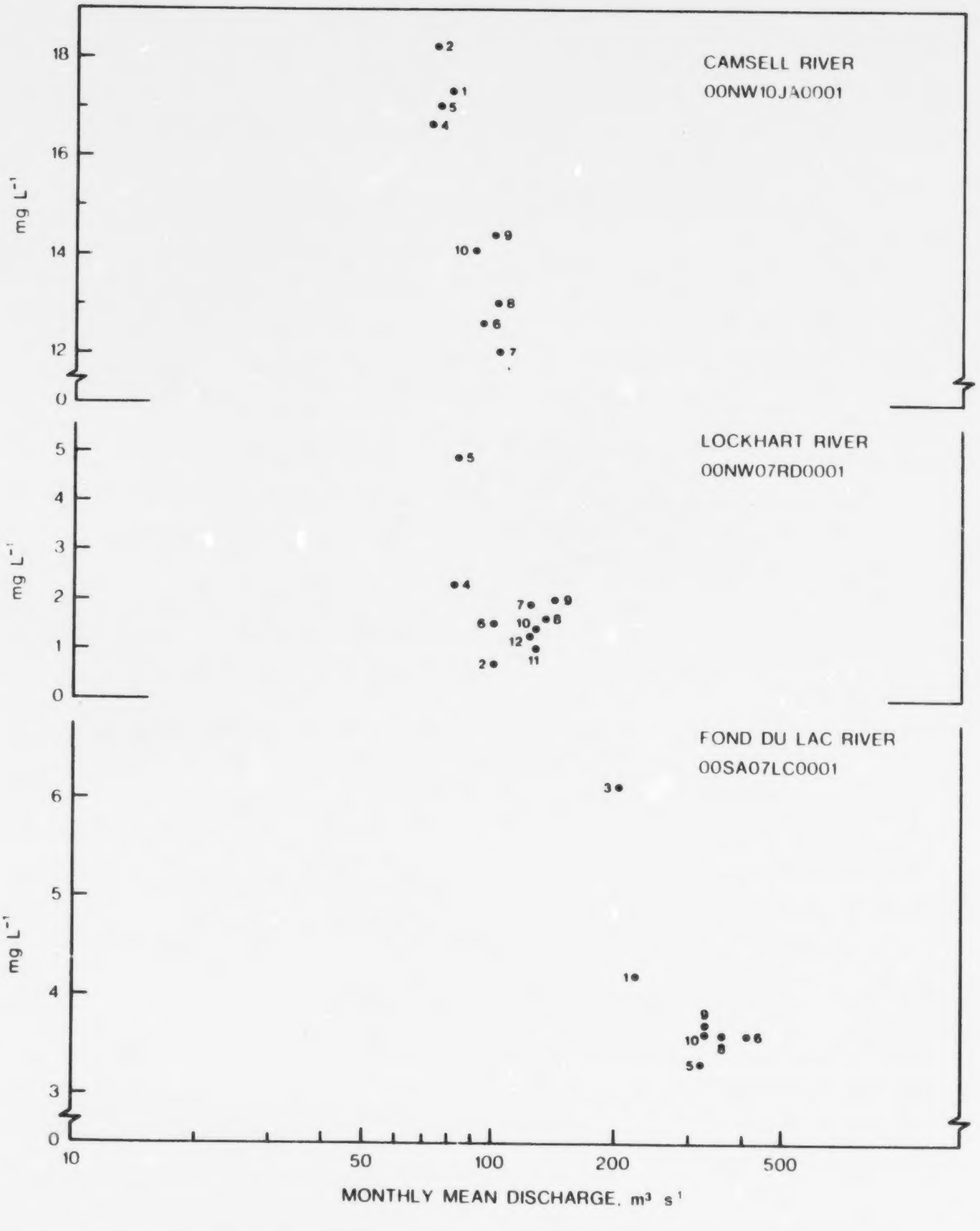

Figure D-3 Seasonal variation of Ca^{2+} in rivers in the Precambrian Shield. Numbers refer to month of the year.

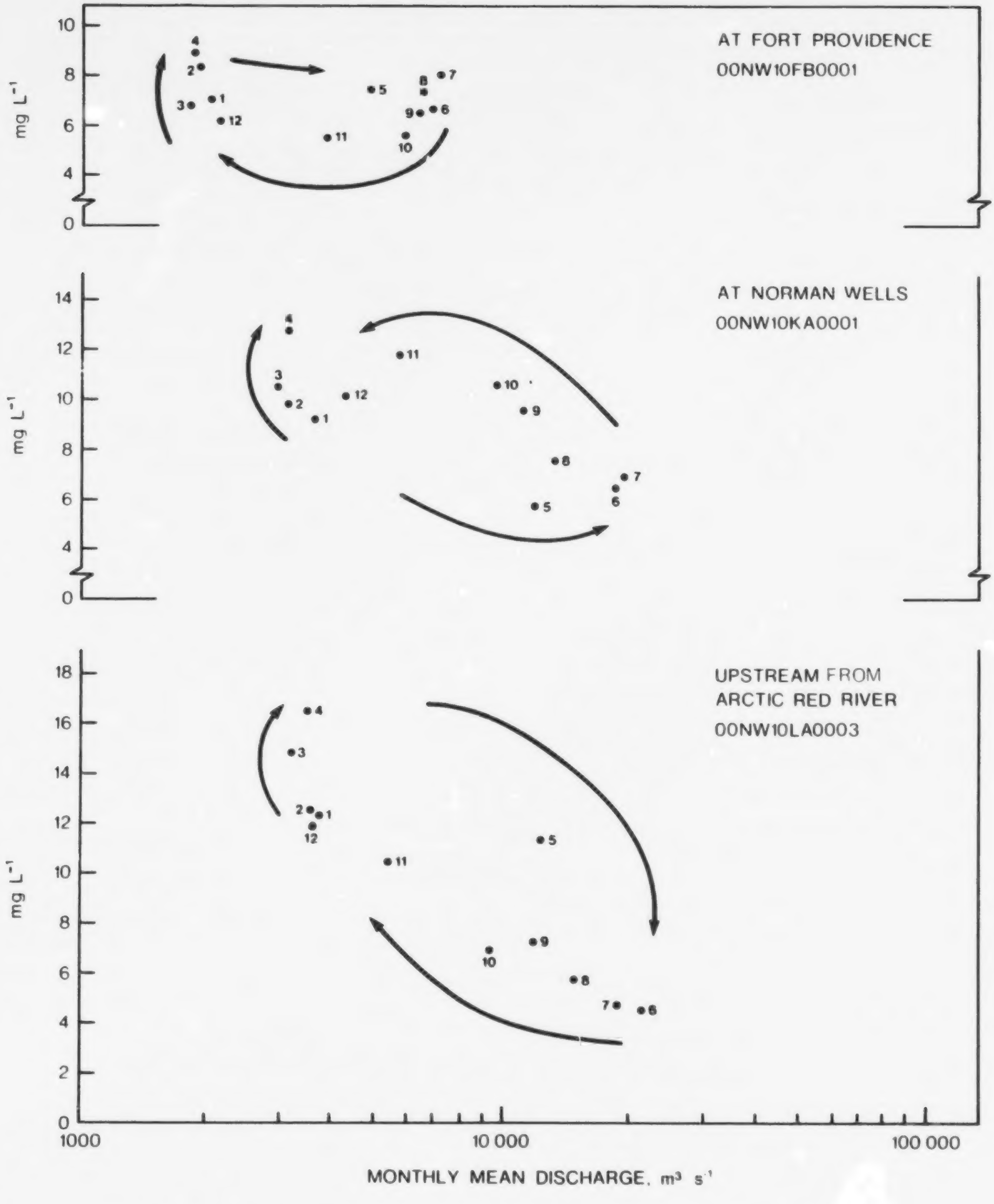

Figure D-4 Seasonal variation of Cl$^-$ at selected sites on the Mackenzie River. Numbers refer to month of the year.

Appendix E

Nutrient, Metal and Organic Parameter Data for the Mackenzie River Subbasins

Table E-1a Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Athabasca River Subbasin

Parameters	n	Mean	Min.	Max.	S.D.	50th	75th	90th
DISSOLVED ORGANIC CARBON								
Upstream from Sunwapta	0							
At Athabasca	26	7.4	2.0	25	4.8	7.0	8.0	12
At Fort McMurray	0							
At Bitumount	0							
Fond du Lac River	0							
TOTAL ORGANIC CARBON								
Upstream from Sunwapta	20	2.2	0	6.0	1.4	2.0	3.0	4.5
At Athabasca	32	12	4.0	28	6.6	9.5	12	23
At Fort McMurray	24	13	2.0	30	5.7	12	14	23
At Bitumount	0							
Fond du Lac River	20	4.5	2.0	7.0	1.3	4.0	5.0	6.5
DISSOLVED NITROGEN								
Upstream from Sunwapta	20							
At Athabasca	21	0.39	0.13	2.3	0.46	0.28	0.37	0.53
At Fort McMurray	0							
At Bitumount	0							
Fond du Lac River	4	0.13	0.12	0.15	0.02	0.13	0.15	
DISSOLVED NO_3^- and NO_2^-								
Upstream from Sunwapta	20	0.233	0.040	1.60	0.351	0.120	0.175	0.540
At Athabasca	134	0.063	<0.001	0.429	0.071	0.040	0.080	0.130
At Fort McMurray	63	0.073	<0.005	0.371	0.070	0.060	0.110	0.158
At Bitumount	6	0.097	0.080	0.100	0.008	<0.100	<0.100	
Fond du Lac River	19	0.036	<0.010	0.160	0.040	0.020	0.050	0.100
TOTAL KJELDAHL NITROGEN								
Upstream from Sunwapta	18	0.2	0.1	0.4	0.1	0.2	0.3	0.4
At Athabasca	21	0.5	0.1	0.8	0.2	0.5	0.5	0.6
At Fort McMurray	13	0.6	0.2	1.7	0.4	0.4	0.6	1.3
At Bitumount	0							
Fond du Lac River	15	0.4	<0.1	1.1	0.3	0.3	0.5	0.6
TOTAL DISSOLVED PHOSPHORUS								
Upstream from Sunwapta	0							
At Athabasca	20	0.007	<0.003	0.017	0.004	0.007	0.009	0.015
At Fort McMurray	0							
At Bitumount	0							
Fond du Lac River	4	0.003	<0.003	0.003	0	<0.003	<0.003	
TOTAL PHOSPHORUS								
Upstream from Sunwapta	20	0.017	<0.003	0.110	0.026	0.008	0.015	0.047
At Athabasca	37	0.018	<0.005	0.100	0.024	<0.005	0.021	0.047
At Fort McMurray	20	0.109	0.010	1.3	0.285	0.029	0.069	0.165
At Bitumount	0							
Fond du Lac River	20	0.010	0.004	0.04	0.008	0.009	0.010	0.014

n = Number of observations.
S.D. = Standard deviation.

Table E-1b Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Peace River Subbasin

Parameters	n	Mean	Min.	Max.	S.D.	50th	75th	90th
DISSOLVED ORGANIC CARBON								
At HWY 29	0							
At Dunvegan	13	2.6	1.0	5.0	1.2	2.0	3.0	4.0
At Peace Point	0							
Smoky River at Watino	25	7.0	2.0	14	3.3	7.0	8.0	12
TOTAL ORGANIC CARBON								
At HWY 29	7	4.6	3.0	9.1	2.1	3.6	4.8	
At Dunvegan	18	12	1.0	44	11	8.0	19	26
At Peace Point	9	21	5.0	51	19	11	34	
Smoky River at Watino	27	13	3.0	37	8.4	11	16	29
DISSOLVED NITROGEN								
At HWY 29	3	0.23	0.19	0.28	0.05	0.22		
At Dunvegan	0							
At Peace Point	0							
Smoky River at Watino	21	0.27	0.08	1.1	0.23	0.22	0.25	0.50
DISSOLVED NO_3^- and NO_2^-								
At HWY 29	6	0.027	<0.005	0.068	0.024	0.022	0.041	
At Dunvegan	29	0.124	0	0.807	0.167	<0.100	<0.100	0.167
At Peace Point	62	0.142	<0.005	4.00	0.504	0.060	0.104	0.210
Smoky River at Watino	99	0.086	<0.001	1.90	0.209	0.040	0.090	0.160
TOTAL KJELDAHL NITROGEN								
At HWY 29	4	0.34	0.1	0.5	0.19	0.37	0.50	
At Dunvegan	18	0.6	0.1	1.9	0.5	0.4	0.9	1.6
At Peace Point	8	1.1	<0.1	5.1	1.7	0.4	1.1	
Smoky River at Watino	21	0.5	0.1	1.9	0.4	0.5	0.6	0.8
TOTAL DISSOLVED PHOSPHORUS								
At HWY 29	0							
At Dunvegan	0							
At Peace Point	0							
Smoky River at Watino	21	0.012	<0.003	0.064	0.014	0.009	0.015	0.018
TOTAL PHOSPHORUS								
At HWY 29	15	0.017	<0.005	0.059	0.015	0.013	0.023	0.036
At Dunvegan	0							
At Peace Point	13	0.119	0.007	1.0	0.277	0.020	0.047	0.315
Smoky River at Watino	12	0.044	<0.005	0.22	0.064	0.013	0.046	0.120

n = Number of observations.
S.D. = Standard deviation.

Table E-1c Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Liard River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TOTAL ORGANIC CARBON								
Upstream from Dease River	6	9.2	<0.5	20	7.7	8.4	16	
At Fort Liard	5	11	1.0	22	8.9	8.0	18	
Upstream from Fort Simpson	33	11	<0.5	46	10	7.0	12	25
South Nahanni River	8	4.4	2.0	9.0	2.5	4.0	6.0	
DISSOLVED NO_3^- and NO_2^-								
Upstream from Dease River	13	0.060	0.009	0.230	0.071	0.020	0.080	0.150
At Fort Liard	26	0.124	<0.005	0.670	0.154	0.074	0.136	0.271
Upstream from Fort Simpson	40	0.116	<0.001	0.850	0.145	0.090	0.135	0.220
South Nahanni River	23	0.497	<0.005	6.000	1.453	0.057	0.100	0.210
TOTAL KJELDAHL NITROGEN								
Upstream from Dease River	2	<0.5	<0.5	<0.5	<0.5			
At Fort Liard	2	<0.5	<0.5	<0.5	<0.5			
Upstream from Fort Simpson	30	0.7	<0.1	2.3	0.5	<0.5	0.7	1.7
South Nahanni River	4	0.3	0.1	0.5	0.2	0.4	0.5	
TOTAL PHOSPHORUS								
Upstream from Dease River	4	0.011	<0.005	0.021	0.008	0.009	0.017	
At Fort Liard	2	0.007	0.007	0.007	0	0.007		
Upstream from Fort Simpson	41	0.185	<0.005	1.30	0.281	0.029	0.320	0.570
South Nahanni River	5	0.046	0.003	0.110	0.054	0.011	0.100	

n = Number of observations.
S.D. = Standard deviation.

Table E-1d Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Hay River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TOTAL ORGANIC CARBON								
Hay River at mouth	25	32	20	39	5.7	32	35	39
DISSOLVED NO_3^- and NO_2^-								
Hay River at mouth	33	0.217	<0.005	0.588	0.196	0.170	0.380	0.520
TOTAL KJELDAHL NITROGEN								
Hay River at mouth	16	1.2	0.7	2.2	0.3	1.2	1.4	1.4
TOTAL PHOSPHORUS								
Hay River at mouth	10	0.053	0.013	0.13	0.037	0.038	0.075	0.114

n = Number of observations.
S.D. = Standard deviation.

Table E-1e Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Great Bear Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TOTAL ORGANIC CARBON								
Great Bear Lake outlet	11	3.5	1.0	7.0	1.6	3.0	4.0	5.0
Camsell River	6	5.5	4.0	7.0	1.2	5.0	7.0	
DISSOLVED NO_3^- and NO_2^-								
Great Bear Lake outlet	21	0.141	0.04	0.250	0.053	0.147	0.170	0.190
Camsell River	25	0.026	<0.001	0.128	0.031	0.010	0.030	0.070
TOTAL KJELDAHL NITROGEN								
Great Bear Lake outlet	13	0.4	<0.1	0.6	0.2	<0.5	<0.5	<0.5
Camsell River	16	0.4	<0.1	0.6	0.2	0.4	0.5	0.6
TOTAL DISSOLVED PHOSPHORUS								
Great Bear Lake outlet	7	0.029	0.001	0.17	0.063	<0.003	0.02	
Camsell River	3	0.003	<0.003	0.003	0	<0.003		

n = Number of observations.
S.D. = Standard deviation.

Table E-1f Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Great Slave Lake Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TOTAL ORGANIC CARBON								
Slave River at Fitzgerald	12	15	5.0	53	15	9.3	12	40
Lockhart River	8	3.1	1.0	5.0	1.4	3.3	4.0	
Yellowknife Bay	14	6.3	3.1	11	2.5	5.3	8.0	10
DISSOLVED NO_3^- and NO_2^-								
Slave River at Fitzgerald	75	0.090	<0.005	0.555	0.130	0.050	0.108	0.350
Lockhart River	18	0.068	<0.001	1.00	0.233	0.010	0.020	0.050
Yellowknife Bay	21	0.851	<0.005	13	2.94	0.060	0.090	0.770
TOTAL KJELDAHL NITROGEN								
Slave River at Fitzgerald	11	0.7	<0.1	2.9	0.8	<0.5	0.6	0.8
Lockhart River	9	0.5	<0.1	1.3	0.5	0.5	0.9	
Yellowknife Bay	13	1.3	0.1	11	2.9	0.5	0.6	1.4
TOTAL PHOSPHORUS								
Slave River at Fitzgerald	31	0.065	<0.005	0.337	0.082	0.043	0.086	0.15
Lockhart River	12	0.007	<0.003	0.042	0.011	0.004	0.005	0.005
Yellowknife Bay	11	0.020	0.004	0.034	0.011	0.021	0.033	0.034

n = Number of observations.
S.D. = Standard deviation.

Table E-1g Percentiles of Nutrient Parameters (mg L^{-1}) at Selected Sites in the Mackenzie River Subbasin

Parameter	n	Mean	Min.	Max.	S.D.	50th	75th	90th
TOTAL ORGANIC CARBON								
At Fort Providence	37	7.3	0	20	3.6	6.0	9.0	12
Near Wrigley	24	11	5.0	27	6.6	8.0	13	23
Near Norman Wells	13	7.8	4.0	17	3.9	6.0	10	12
Upstream from Arctic Red River	49	11	<0.5	31	6.9	8.0	13	25
DISSOLVED NITROGEN								
At Fort Providence	18	0.29	0.08	0.55	0.14	0.26	0.38	0.50
Near Wrigley	0							
Near Norman Wells	0							
Upstream from Arctic Red River	12	0.25	0.13	0.51	0.10	0.25	0.28	0.32
DISSOLVED NO_3^- and NO_2^-								
At Fort Providence	58	0.084	<0.001	0.520	0.100	0.042	0.120	0.220
Near Wrigley	26	0.088	<0.001	0.210	0.057	0.090	0.120	0.180
Near Norman Wells	82	0.181	<0.005	5.00	0.552	0.119	0.160	0.203
Upstream from Arctic Red River	68	0.142	<0.001	1.10	0.198	0.085	0.165	0.280
TOTAL KJELDAHL NITROGEN								
At Fort Providence	38	0.6	<0.1	3.0	0.5	<0.5	0.5	0.9
Near Wrigley	23	0.7	0.3	2.2	0.5	0.5	0.7	1.2
Near Normal Wells	7	0.4	<0.1	0.6	0.2	<0.5	0.5	
Upstream from Arctic Red River	34	0.6	<0.1	1.3	0.3	0.5	0.6	1.1
TOTAL DISSOLVED PHOSPHORUS								
At Fort Providence	22	0.010	0.001	0.022	0.007	0.009	0.013	0.020
Near Wrigley	3	0.003	<0.003	0.004	0.001	<0.003		
Near Norman Wells	3	0.007	<0.003	0.010	0.004	0.007		
Upstream from Arctic Red River	14	0.015	<0.002	0.069	0.018	0.011	0.014	0.032
TOTAL PHOSPHORUS								
At Fort Providence	0							
Near Wrigley	22	0.062	0.003	0.360	0.084	0.041	0.057	0.089
Near Norman Wells	34	0.039	<0.005	0.359	0.067	0.013	0.045	0.098
Upstream from Arctic Red River	0							

n = Number of observations.
S.D. = Standard deviation.

Table E-2a Extractable Metal Concentrations (mg L^{-1}) in Rivers in the Athabasca River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	1623	<0.004	0.05	<0.01	0.01
Al	2044	<0.006	146.0	0.25	1.09
Ba	2322	<0.05	1.70	<0.10	0.11
Cd	2001	<0.001	0.01	<0.001	0.001
Co	2171	<0.001	0.05	<0.01	0.005
Cr	2279	<0.01	0.07	<0.01	0.012
Cu	2961	<0.001	0.20	0.002	0.006
Fe	2361	<0.04	>5.0	0.85	2.04
Mn	5289	<0.004	7.95	0.04	0.105
Mo	1816	<0.05	0.10	<0.05	0.06
Ni	2120	<0.001	0.09	0.004	0.008
Pb	2685	<0.001	0.04	<0.004	0.004
Sb	659	<0.008	0.20	<0.40	0.33
Sr	1935	<0.01	1.50	0.17	0.19
Tl	849	<0.10	0.30	<0.20	0.16
V	1148	<0.001	0.45	<0.05	0.03
Zn	2818	<0.001	0.33	0.003	0.012

n = Number of observations.

Table E-2b Extractable Metal Concentrations (mg L^{-1}) in Lakes in the Athabasca River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	27	<0.003	<0.01	<0.01	0.009
Al	17	<0.10	<0.10	<0.10	<0.10
Ba	16	<0.10	<0.10	<0.10	<0.10
Cd	46	<0.001	0.002	<0.001	0.001
Co	49	<0.001	0.006	<0.02	0.005
Cr	23	<0.01	<0.01	<0.01	<0.01
Cu	69	<0.001	0.50	0.004	0.024
Fe	70	<0.03	0.61	0.05	0.09
Mn	188	<0.008	6.9	0.017	0.089
Mo	22	<0.05	0.10	<0.10	0.088
Ni	72	<0.001	0.12	0.003	0.013
Pb	53	<0.001	0.04	<0.006	0.007
Sr	15	<0.02	0.07	<0.02	0.023
Zn	83	<0.001	0.53	0.006	0.021

n = Number of observations.

Table E-2c Extractable Metal Concentrations (mg L^{-1}) in Rivers in the Peace River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	200	<0.004	0.05	<0.01	0.01
Al	253	<0.10	146.0	0.32	1.47
Ba	259	<0.05	1.70	<0.10	0.12
Cd	286	<0.0002	0.01	<0.001	0.001
Co	331	<0.001	0.05	<0.01	0.005
Cr	260	<0.01	0.07	<0.01	0.01
Cu	393	<0.001	0.20	0.002	0.006
Fe	335	<0.04	34.4	0.91	2.25
Mn	397	<0.008	2.10	0.04	0.105
Mo	239	<0.05	0.10	<0.05	0.06
Ni	334	<0.001	0.09	0.004	0.008
Pb	370	<0.001	0.03	<0.004	0.004
Sb	90	<0.008	0.50	<0.40	0.34
Sr	265	<0.02	1.50	0.16	0.19
Tl	117	<0.10	0.30	<0.20	0.16
V	128	<0.001	0.45	<0.05	0.04
Zn	371	<0.001	0.27	0.004	0.013

n = Number of observations.

Table E-2d Extractable Metal Concentrations (mg L^{-1}) in Rivers in the Liard River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	29	<0.004	0.01	<0.01	0.009
Al	25	<0.06	3.70	0.20	0.69
Ba	17	<0.10	0.30	0.06	0.09
Cd	107	<0.001	0.01	<0.001	0.002
Co	119	<0.001	0.02	0.001	0.007
Cr	125	<0.006	0.34	<0.01	0.014
Cu	179	<0.001	0.09	0.002	0.010
Fe	175	<0.04	27.0	0.56	1.97
Mn	178	<0.006	0.69	0.03	0.07
Mo	109	<0.01	0.31	<0.05	0.06
Ni	158	<0.001	0.53	0.005	0.02
Pb	175	<0.001	0.05	<0.01	0.006
Sb	4	<0.01	0.10	0.035	0.088
Sr	86	0.09	0.33	0.16	0.16
Tl	4	0.001	<0.001	<0.001	<0.001
V	84	<0.001	0.36	<0.05	0.06
Zn	212	<0.001	0.27	0.007	0.02

n = Number of observations.

Table E-2e Extractable Metal Concentrations (mg L^{-1})
in Rivers in the Hay River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	25	<0.01	0.05	<0.01	0.01
Al	25	<0.10	1.40	0.21	0.41
Ba	28	<0.05	0.10	<0.10	0.09
Cd	41	<0.001	0.003	<0.001	0.001
Co	46	<0.001	0.019	0.001	0.004
Cr	43	<0.01	0.01	<0.01	0.01
Cu	48	<0.001	0.02	0.003	0.004
Fe	44	0.69	11.60	1.90	2.47
Mn	48	<0.01	0.37	0.06	0.07
Mo	40	<0.05	0.10	<0.05	0.05
Ni	44	<0.001	0.027	0.008	0.009
Pb	49	<0.001	0.008	<0.001	0.003
Sb	13	<0.008	0.50	<0.04	0.35
Sr	43	0.10	0.34	0.15	0.15
Tl	16	<0.10	0.20	<0.20	0.16
V	34	<0.05	<0.05	<0.05	<0.05
Zn	48	<0.001	0.050	0.004	0.008

n = Number of observations.

Table E-2f Extractable Metal Concentrations (mg L^{-1})
in Rivers in the Great Bear Lake Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	4	<0.003	<0.003	<0.005	<0.003
Al	24	<0.06	0.10	<0.10	0.09
Ba	31	<0.05	0.10	<0.05	0.07
Cd	71	<0.001	0.02	<0.001	0.002
Co	76	<0.001	0.015	<0.002	0.003
Cr	51	<0.006	0.015	<0.01	0.011
Cu	83	<0.001	0.580	<0.01	0.017
Fe	76	<0.04	1.80	0.05	0.18
Mn	77	<0.01	0.06	<0.01	0.01
Mo	53	<0.05	0.05	<0.05	<0.05
Ni	66	<0.001	<0.012	<0.01	<0.01
Pb	77	<0.001	0.006	0.004	0.004
Sr	34	0.05	0.66	0.10	0.15
V	40	<0.001	0.05	<0.05	0.04
Zn	84	<0.001	0.029	0.001	0.006

n = Number of observations.

Table E-2g Extractable Metal Concentrations (mg L^{-1}) in Lakes in the Great Bear Lake Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	10	<0.003	0.008	<0.007	0.006
Cd	14	<0.001	0.002	<0.002	0.001
Co	18	<0.001	0.02	<0.02	0.006
Cr	2	<0.011	<0.011	<0.011	<0.011
Cu	19	<0.001	0.31	0.004	0.03
Fe	20	<0.04	0.61	0.045	0.10
Mn	22	<0.01	0.06	0.013	0.02
Mo	8	<0.05	0.10	<0.10	0.09
Ni	20	<0.004	0.015	0.003	0.012
Pb	17	0.005	0.022	0.012	0.010
Zn	21	<0.002	0.07	0.009	0.015

n = Number of observations.

Table E-2h Extractable Metal Concentrations (mg L^{-1}) in Rivers in the Great Slave Lake Subbasin

Metal	n	Min.	Max.	Median	Mean
Al	11	0.10	3.00	0.50	0.82
Ba	16	<0.10	0.22	0.05	0.08
Cd	16	<0.001	0.05	0.002	0.013
Co	16	<0.001	0.005	<0.002	0.002
Cr	10	<0.01	<0.01	<0.01	<0.01
Cu	28	<0.01	0.02	0.002	0.007
Fe	28	0.10	>5.0	1.33	2.12
Mn	35	<0.01	0.44	<0.05	0.06
Mo	10	<0.10	<0.10	<0.10	<0.10
Ni	11	<0.005	0.01	0.007	0.007
Pb	19	<0.001	0.008	<0.005	0.005
Sr	3	<0.05	0.10	<0.05	0.06
V	5	<0.001	0.01	0.01	0.01
Zn	19	<0.01	0.09	0.015	0.02

n = Number of observations.

Table E-2i Extractable Metal Concentrations (mg L^{-1}) in Lakes in the Great Slave Lake Subbasin

Metal	n	Min.	Max.	Median	Mean
Cd	16	<0.001	0.002	0.001	0.001
Co	17	<0.001	0.006	0.002	0.002
Cr	4	<0.010	<0.015	<0.013	0.013
Cu	35	<0.001	0.50	0.007	0.033
Fe	33	<0.03	0.21	0.05	0.07
Mn	23	<0.008	0.014	<0.01	0.012
Mo	10	<0.10	<0.10	<0.10	<0.10
Ni	36	<0.001	0.016	0.004	0.013
Pb	21	<0.001	0.04	<0.006	0.007
Zn	35	<0.008	0.53	0.006	0.026

n = Number of observations.

Table E-2j Extractable Metal Concentrations (mg L^{-1}) in Rivers in the Mackenzie River Subbasin

Metal	n	Min.	Max.	Median	Mean
Ag	40	<0.003	0.25	<0.005	0.011
Al	59	<0.06	5.50	<0.10	0.29
Ba	96	<0.05	0.35	<0.10	0.08
Cd	610	<0.0001	0.039	<0.001	0.001
Co	619	<0.001	0.04	0.001	0.003
Cr	540	<0.006	0.05	<0.01	0.011
Cu	789	<0.001	0.58	0.002	0.007
Fe	711	<0.04	64.00	0.35	2.30
Mn	736	<0.01	4.2	0.01	0.07
Mo	528	<0.01	0.56	<0.05	0.06
Ni	608	<0.001	0.08	0.005	0.008
Pb	726	<0.001	0.94	<0.004	0.006
Sr	491	<0.005	5.10	0.19	0.42
Tl	3	<0.10	0.10	<0.10	<0.10
V	499	<0.001	0.34	<0.05	0.05
Zn	744	<0.001	0.34	0.005	0.02

n = Number of observations.

Table E-3a Annual Mean Concentration (mg L^{-1}) of Extractable Metals in the Athabasca River at Athabasca

Year	Mn	Al	Fe	Cu	Sr
1960	<0.01		0.83	0.01	
1961	0.03		0.71	<0.01	
1962	<0.01		0.22	0.01	
1963					
1964					
1965					
1966					
1967					
1968					
1969	<0.01			<0.01	
1970	<0.01			<0.01	
1971	0.06	1.70	1.45	0.001	0.18
1972	0.22	0.18	4.68	0.008	0.22
1973	0.08	0.79	2.05	0.004	0.25
1974	0.03	0.27	0.81	0.003	0.21
1975	0.06	0.17	0.95	0.003	0.22
1976	0.07	0.42	1.42	0.002	0.31
1977	0.07	0.42	1.39	0.002	0.24
1978	0.04	0.18	0.55	0.001	0.34
1979	0.05	0.28		0.004	0.22

Table E-3b Annual Mean Concentration (mg L^{-1}) of Extractable Metals in the Smoky River at Watino

Year	Al	V	Cr	Mn	Fe	Co	Li	Ni	Cu	Zn	Sr	Cd	Ba
1960													
1961													
1962													
1963													
1964													
1965													
1966													
1967				0.01					<0.01	<0.01			
1968				<0.01									
1969				<0.01					<0.01	<0.01			
1970				<0.01					<0.01	<0.01			
1971	1.80	<0.05	<0.010	0.04	<0.01		0.007	<0.01	0.001	0.004	0.23		
1972	0.67	0.15	0.040	0.77	17.5	0.015	0.040	0.032	0.027	0.13	0.31		
1973	1.95	<0.05	0.010	0.18	5.3	0.005	0.014	0.011	0.007	0.026	0.26	<0.001	0.2
1974	0.70		<0.010	0.06	1.6	0.003		0.004	0.005	0.013	0.24	0.001	0.1
1975	0.69		<0.015	0.14	2.6	0.003		0.005	0.007	0.013	0.28	<0.001	0.13
1976	2.26	0.07	<0.015	0.22	7.3	0.005		0.013	0.007	0.026	0.29	0.001	0.22
1977	1.54	0.06	<0.015	0.18	4.0	0.004		0.009	0.006	0.018	0.31	<0.001	0.18
1978	0.55	0.002	<0.015	0.03	0.6	0.002	0.006	0.003	0.002	0.004	0.29	<0.001	0.06
1979	2.51	0.012	0.018	0.29	7.3	0.006	0.10	0.015	0.004	0.040	0.31	<0.001	0.25

Table E-3c Annual Mean Concentration (mg L^{-1}) of Extractable Metals in the Mackenzie River near Norman Wells

Year	Fe	Cu	Zn
1960	2.01	<0.01	
1961			
1962			
1963			
1964			
1965			
1966			
1967			
1968			
1969		<0.01	<0.01
1970		<0.01	<0.01
1971			
1972			
1973			
1974			
1975	1.06	0.007	0.015
1976	0.78	0.004	0.016
1977			
1978			
1979	1.35	0.004	0.007

Table E-4a Concentrations (μg L^{-1}) in Water of Organic Parameters in Rivers of the Athabasca River Subbasin

Parameter	n	Min.	Max.	Median
Phenols (mg L^{-1})	930	<0.001	0.130	0.002
p,p'-DDT	483	<0.004	<0.004	<0.004
o,p -DDT	110	<0.001	<0.001	<0.001
p,p'-TDE	483	<0.002	<0.002	<0.002
p,p'-DDE	483	<0.001	<0.002	<0.001
p,p'-Methoxychlor	483	<0.002	<0.012	<0.012
α-Endosulfan	482	<0.001	<0.001	<0.001
β-Endosulfan	483	<0.003	<0.003	<0.003
α-(cis)chlordane	162	<0.002	<0.003	<0.003
γ-(trans)chlordane	162	<0.002	<0.002	<0.002
γ-BHC	587	<0.007	0.0013	<0.007
α-BHC	250	<0.001	0.010	0.003
Mirex	111	<0.001	<0.001	<0.001
Aldrin	468	<0.007	<0.002	<0.007
Endrin	174	<0.001	<0.003	<0.002
Dieldrin	482	<0.0018	<0.003	<0.002
Arochlor 1254	648	<0.002	0.019	<0.03
Arochlor 1248	649	<0.002	0.165	<0.02
Arochlor 1260	605	<0.005	0.007	<0.055
Azinphosmethyl	12	<0.100	<0.200	<0.100
Imidan	24	<0.200	<0.200	<0.200
Disulfoton	24	<0.02	<0.02	<0.02
Crufomate	24	<0.20	<0.20	<0.20
Parathion	84	<0.01	<0.02	<0.01
Methyl-parathion	24	<0.02	<0.02	<0.02
Malathion	84	<0.01	<0.05	<0.01
Fenchlorphos	24	<0.02	<0.02	<0.02
Diazinon	79	<0.02	<0.02	<0.02
Phorate	24	<0.02	<0.02	<0.02
Ethion	84	<0.01	0.01	<0.01
Carbophenothion	84	<0.02	<0.02	<0.02
2,4-D	205	<0.004	0.05	<0.004
2,4,5-T	203	<0.002	0.009	<0.002
MCPA	171	<0.20	<0.20	<0.20
Fenoprop	111	<0.004	<0.004	<0.004
2,4-DB	205	<0.009	<0.009	<0.009
Dichlorprop	205	<0.004	0.010	<0.004

n = Number of observations.

Table E-4b Concentrations (µg L^{-1}) in Water of Organic Parameters in Lakes of the Athabasca River Subbasin

Parameter	n	Min.	Max.	Median
Phenols (mg L^{-1})	4	<0.002	0.080	0.03
p,p'-DDT	1	<0.004		
p,p'-TDE	1	<0.002		
p,p'-DDE	1	<0.001		
p,p'-Methoxychlor	1	<0.012		
α-Endosulfan	1	<0.001		
β-Endosulfan	1	<0.003		
γ-BHC	1	<0.0007		
Aldrin	1	<0.0007		
Dieldrin	1	<0.002		
Arochlor 1254	4	<0.024	<0.028	<0.024
Arochlor 1248	4	<0.055	1.70	<0.777
Arochlor 1260	4	1.90	2.40	2.00

n = Number of observations.

Table E-4c Concentrations (μg L^{-1}) in Water of Organic Parameters in Rivers of the Peace River Subbasin

Parameter	n	Min.	Max.	Median
Phenols (mg L^{-1})	96	<0.001	0.034	0.002
p,p'-DDT	44	<0.004	<0.012	<0.004
o,p -DDT	12	<0.001	<0.001	<0.001
p,p'-TDE	44	<0.001	<0.005	<0.002
p,p'-DDE	44	<0.001	<0.001	<0.005
p,p'-Methoxychlor	44	<0.001	<0.012	<0.012
α-Endosulfan	43	<0.001	<0.010	<0.001
β-Endosulfan	44	<0.003	<0.010	<0.003
α-(cis)Chlordane	17	<0.002	<0.005	<0.003
γ-(trans)Chlordane	17	<0.002	<0.005	<0.002
γ-BHC	54	<0.0007	0.001	<0.0008
α-BHC	24	<0.001	0.008	0.004
Mirex	12	<0.001	<0.001	<0.001
Aldrin	41	<0.0007	<0.005	<0.0007
Endrin	17	<0.002	<0.010	<0.002
Dieldrin	44	<0.002	<0.005	<0.002
Arochlor 1254	56	<0.002	<0.100	<0.03
Arochlor 1248	56	<0.002	<0.100	<0.02
Arochlor 1260	51	<0.005	<0.100	<0.055
Azinphosmethyl	2	<0.100	<0.100	<0.100
Imidan	4	<0.200	<0.02	<0.110
Disulfoton	4	<0.200	<0.10	<0.105
Crufomate	4	<0.010	<0.020	<0.015
Parathion	14	<0.020	<0.010	<0.015
Methyl-parathion	4	<0.010	<0.050	<0.050
Malathion	14	<0.020	<0.020	<0.020
Fenchlorphos	4	<0.020	<0.020	<0.020
Diazinon	13	<0.020	<0.020	<0.010
Phorate	4	<0.020	<0.020	<0.020
Ethion	14	<0.020	<0.020	<0.020
Carbophenothion	14	<0.004	<0.004	<0.004
2,4-D	21	<0.002	<0.002	<0.002
2,4,5-T	21	<0.002	<0.009	<0.002
MCPA	18	<0.200	<0.200	<0.200
Fenoprop	12	<0.004	<0.009	<0.004
2,4-DB	21	<0.009	<0.009	<0.009
Dichlorprop	21	<0.004	<0.004	<0.004

n = Number of observations.

Appendix F

Comparison with Guidelines for the Protection of Freshwater Aquatic Life

Table F-1 Comparison with Guidelines for the Protection of Freshwater Aquatic Life

Parameter	Guideline	90th Percentile*	
		Rivers	Lakes
TDS	Max. 400 mg L^{-1}	9829 G.S.	237 Ath
pH	6.5-9.0 units	8.6 Hay	8.6 Peace
NH_3	Max. 0.02 mg L^{-1}	<0.10 Ath, Peace	-
NO_3^-	Max. 90 mg L^{-1}	0.58 Hay	43 G.B.
TP	0.10 mg L^{-1} flowing waters 0.05 mg L^{-1} waters flowing into lakes and reservoirs 0.025 mg L^{-1} lakes and reservoirs	0.20 Mac	0.036 G.B.
Ag	0.1 μg L^{-1}	<0.012 Liard	<0.01 Ath
Cd	0.2 μg L^{-1}	<0.050 G.S.	0.002 all
Cr	0.04 mg L^{-1}	<0.015 all	<0.015 Ath
Cu	0.002 mg L^{-1}	0.02 Liard	0.073 G.S.
Hg	0.2 μg L^{-1}	0.110 Hay	0.13 Ath
Ni	0.25 mg L^{-1}	0.020 Liard	0.009 Ath, G.B.
Pb	0.01 mg L^{-1}	0.010 Liard	0.019 G.B.
Se	0.01 mg L^{-1}	0.0006 Mac	0.0003 Ath
Zn	0.10 mg L^{-1}	0.042 G.S.	0.050 Ath
Phenolic compounds	0.001 mg L^{-1}	0.014†	No organic data for lakes
Aldrin and dieldrin	0.001 μg L^{-1}	<0.002	
γ-BHC	0.01 μg L^{-1}	<0.001	
DDT	0.001 μg L^{-1}	<0.004	
Diazinon	0.08 μg L^{-1}	<0.02	
α-Endosulfan	0.003 μg L^{-1}	<0.001	
β-Endosulfan	0.003 μg L^{-1}	<0.003	
Endrin	0.002 μg L^{-1}	<0.003	
Guthion	0.005 μg L^{-1}	<0.10	
Malathion	0.1 μg L^{-1}	<0.05	
p,p'-Methoxychlor	0.03 μg L^{-1}	<0.012	
Mirex	0.001 μg L^{-1}	<0.001	
Parathion	0.008 μg L^{-1}	<0.02	
PCBs (total)	0.001 μg L^{-1}	<0.06	

* The 90th percentiles for the subbasins presented are the maximum percentiles of all the subbasins.

†All values for organic parameters in rivers apply to the Athabasca and Peace subbasins.

NOTE: Ath = Athabasca; G.B. = Great Bear; G.S. = Great Slave; Mac = Mackenzie.
Units of the percentile values are the same as those for the Guidelines.

Sources: Environment Canada (1981); U.S. Environmental Protection Agency (1976, 1979); International Joint Commission (1977).